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The results of these protype tests showed the following:

1. The unit reduced the hydraulic wasteload of conventional blanching and cooling by several orders of magnitude and the organic wasteload by as much as 80%.

2. The steam efficiency of the blancher was 85%, which exceeds by 17 times that measured for a conventional stean blancher.

3. Sensory tests were done only with the snap-beans and lima beans. Those samples produced by the vibratory spiral blancher-cooler were judged either equal or superior in flavor and texture to those conventionally blancher and cooler.

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VIBRATORY SPIRAL BLANCHER-COOLER

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the results of a two year evaluation of a unique vegetable blanching and cooling system. Study results indicate that the vibratory spiral blancher-cooler will significantly reduce the wasteloads and energy consumption associated with these unit processes. Study results should be of interest to processors of frozen and canned vegetables, food process researchers, and manufacturers of equipment for the user industries. Further information on the project can be obtained by contacting the Food and Wood Products Branch, Industrial Pollution Control Division, IERL-Ci.

David G. Stephan
Director
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ABSTRACT

The objective of this demonstration project was to test the commercial feasibility of the vibratory spiral blancher-cooler, a newly designed steam blancher and air cooler that previous small scale tests showed could reduce the wasteload and energy consumption of preparing vegetables for freezing.

A prototype vibratory spiral blancher-cooler was designed and constructed. This unit was installed at a vegetable freezing plant for two processing seasons. Snap beans and lima beans were tested for both processing seasons; a few brief experimental runs with brussels sprouts, cauliflower and broccoli were done during one season.

The results of these prototype tests showed the following:

1. The unit reduced the hydraulic wasteload of conventional blanching and cooling by several orders of magnitude and the organic wasteload by as much as 80%.

2. The steam efficiency of the blancher was 85%, which exceeds by 17 times that measured for a conventional steam blancher.

3. The vibratory spiral blancher-cooler processed over 2000 kg/hr of snap beans and over 1200 kg/hr of lima beans. Minor equipment modification would be required to achieve full capacity with broccoli, brussels sprouts, and cauliflower.

4. It was easy to clean after use. Product leaving the cooler had microbial counts far below the accepted practice in vegetable freezing plants.

5. Sensory tests were done only with the snap-beans and lima beans. Those samples produced by the vibratory spiral blancher-cooler were judged either equal or superior in flavor and texture to those conventionally blanched and cooled.

6. Although the operating costs of the vibratory spiral blancher-cooler were higher than those of a conventional water blancher and a flume cooler, a doubling of the combined costs of utilities and waste treatment would make the operating costs of the two equal.

This report was submitted in fulfillment of Grant No. S-803312 by the American Frozen Food Institute under the partial sponsorship of the U. S. Environmental Protection Agency. Work was conducted by the U. S.

Department of Agriculture Western Regional Research Center under contract to the American Frozen Food Institute. This report covers the period July 15, 1974 to January 17, 1977.

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SECTION 1

INTRODUCTION

A major conclusion of reports on the wasteload of vegetable processing is that the blanching operation produces a large percentage of a vegetable processing plant's wasteload (Weckel, et al., 1968; NCA, 1971; Ralls and Mercer, 1973; Soderquist, 1975). The work presented in this report describes a technique that reduces the wasteload from both blanching and the subsequent cooling of vegetables. It accomplishes this waste reduction with a large savings in the use of steam and with a design requiring less floor space than a conventional steam blancher.

The prototype vibratory spiral blancher-cooler, whose design and performance is described here, is a demonstration of a series of developments of the work done at the Western Regional Research Center on steam blanching and cooling of vegetables before freezing (Brown, et al., 1974; Bomben, et al., 1975). Each of these developments was tested at the Western Regional Research Center to the small pilot plant stage. The prototype vibratory spiral blancher-cooler pilot plant incorporated all of these developments, and it was of adequate capacity to demonstrate the suitability of these concepts for use in the commercial processing of frozen vegetables.

The use of vibratory conveyors for steam blanching was developed to reduce the size and improve the heat efficiency of steam blanchers (Brown, et al., 1974). The spiral vibratory conveyor allowed for a more compact design than did the conventional belt conveyor in steam blanchers. In comparison to water blanchers, steam blanchers are large and have a low thermal efficiency. The lower wasteload of steam blanching as compared to water blanching (Ralls and Mercer, 1973; Lund, 1974) has not been sufficient for most processors to justify its use in place of water blanching. The thermal efficiency of blanchers has not been a subject of much interest until the recent concern about the cost and availability of energy sources.

Using steam blancher condensate as a spray during air cooling was another development incorporated into the vibratory spiral blancher-cooler. This technique reduced the wasteload of both blanching and cooling (Bomben, et al., 1975). By using air instead of flume cooling, the hydraulic wasteload of cooling was reduced enormously, and the organic wasteload produced by the leaching of solids in the flume was eliminated. By using the steam blancher condensate as a spray during air cooling, the wasteload of both blanching and cooling was reduced to the unevaporated and unabsorbed liquid leaving the cooler.

The technique of Individual Quick Blanching (IQB) was included in the vibratory spiral blancher-cooler since it gave an additional means of

reducing the size of the blancher (Lazar, et al., 1971). The heating and holding technique in addition provided uniform blanching of vegetables.

The prototype vibratory spiral blancher-cooler was installed and tested at a frozen vegetable plant (Patterson Frozen Foods, Patterson, California) from August, 1975 to January, 1977. Snap beans and lima beans were tested during two processing seasons. A few brief runs were made with brussels sprouts, cauliflower and broccoli during the second processing season. Although the tests described in this report apply to frozen vegetables, the blancher (without the cooler) could be used in the vegetable canning industry.

SECTION 2

CONCLUSIONS

The vibratory spiral blancher-cooler was able to blanch and cool vegetables at a rate far exceeding its design capacity of 900 kg/hr for snap beans. Snap beans were blanched at over 2000 kg/hr and lima beans were blanched at 1200 kg/hr. Modification of the equipment would be required to achieve full capacity for broccoli, brussels sprouts and cauliflower. The vibratory cooler was operated in two different modes; vegetables were either conveyed up or down. Higher capacities were achieved with vegetable flowing down the cooler. With product moving down the cooling vibratory spiral, snap beans, lima beans, brussels sprouts, cauliflower and broccoli could all be processed. With product moving up the cooling spiral consistent product flow could be achieved only with snap beans.

The wasteload produced by the vibratory spiral blancher-cooler (1 L/kkg) and 0.9 kg BOD/kkg lima beans) was much less than that produced by conventional blanching and cooling (1000 L/kkg and 4.4 kg BOD/kkg lima beans). The steam efficiency of the vibratory spiral blancher (85%) was much higher than that measured on a production line steam blancher (5%) and those reported for other blanchers (27 - 60%).

Sensory tests of snap beans and lima beans produced by the vibratory spiral blancher-cooler showed them to be either better or the same in flavor and texture as those produced in a conventional blancher on the production line. Total aerobic counts made on snap beans and lima beans leaving the vibratory spiral cooler were considerably lower than the limits accepted by sanitary practice in the vegetable freezing industry.

The low capital investment required by water blanching makes its cost significantly less than other blanching techniques. A doubling of the combined cost of energy and wastewater treatment would make the cost of blanching and cooling with the vibratory spiral blancher-cooler equal to that of a water blancher and flume cooler. When comparing blanching alone (without cooling), water blanching remained the lowest cost method, but again, doubling of the combined cost of energy and wastewater treatment would make the cost of the vibratory spiral blancher equal. The cost of blanching with the vibratory spiral blancher was less than that of either the hydrostatic steam blancher or hot-gas blancher.

SECTION 3

RECOMMENDATIONS

Since the vibratory spiral blancher-cooler tested in this project was large enough to be representative of a typical full-scale production unit, there is no need to test the design on a larger scale. Scale up to a larger size can be readily accomplished; designs with capacities 5 and 10 times that of the pilot plant are available from the manufacturer of the pilot plant. However, it is recommended that any private company considering the installation of a full-size vibratory spiral blancher-cooler utilize the pilot plant constructed under this project to obtain design and production data for its particular use.

Although the results of the project indicate that broccoli, brussels sprouts and cauliflower can be processed with this equipment, full capacity for these vegetables would require an increase in the size of the holder and, in the case of broccoli, an increase in the sizes of the inlet and discharge cross-sections. Before a full size unit for these vegetables can be designed, the exact dimensions of these changes need to be determined by testing the vegetables on a modified prototype.

All the work done in this project was aimed at preparing vegetables for freezing, and hence cooling was always used. In blanching for canning, cooling is an unnecessary step, but the advantages of compactness and high steam efficiency for the vibratory spiral blancher still have applicability for canning. In addition, blanching effluent could be entirely eliminated if it were suitable for use as a brine for canning vegetables. Thus, it is recommended that the vibratory spiral blancher be tested in a vegetable canning plant and that the use of the blancher condensate as a canning brine be evaluated.

SECTION 4

EXPERIMENTAL PROCEDURES

Prototype Design

The prototype pilot plant, which is shown schematically in Figure 1, was designed with a 0.91 kkg/hr (one ton per hour) capacity based on a conveyor loading of 4.9 kg/m^2 (one pound/ft^2), and a bulk density of 641 kg/m^3 (40 lb/ft^3) for the vegetables. The equipment was constructed using a standard design for vibratory spiral conveyors. The pilot plant occupied a floor area of 3.7 by 3.2 m (12 ft by 10-1/2 ft) and it had a shipping weight of 8.6 kkg (19000 lbs).

The pilot plant was operated in two different modes. Figures 2 and 3 show the pilot plant as it was operated during the 1975 vegetable processing season with product moving up the cooling spiral. Figures 4 and 5 show the pilot plant as it was operated during the 1976 season with product moving down the cooling spiral. The movement of product up the cooling spiral gave a design of less height, 4.2 m (13 ft - 11 in.), versus that, 6.1 m (19 ft - 11 in.), for product movement down the cooling spiral. The down-flow arrangement was necessary since the vibration could not move some vegetables upward.

The pilot plant consisted of six units: feeder, heater, holder, cooler, air blower with filter, and condensate spray system. These units are indicated in Figure 1, and they are shown in more detail in Figures 2, 3, 4 and 5.

For operation with the up-flow cooler, the feeder-elevator consisted of an inclined, cleated (3.8 cm; 1-1/2 in.) rubber belt conveyor 30.5 cm wide by 7.6 m long (12 in. by 25 ft), a 746 W (1 hp.) variable speed drive and a 1.4 m^3 (50 ft^3) feed bin. For operation with the down-flow cooler, the above feeder was used as an elevator to the feed bin (0.057 m^3; 2 ft^3) of a smaller inclined, cleated (3.8 cm; 1-1/2 in.) belt conveyor 20.3 cm wide by 3.0 m long (8 in. by 10 ft) driven by a 746 W (1 hp) variable speed electrical drive.

The heater was a vibratory spiral enclosed in a double wall insulated [2.5 cm (1 in.) air spacing] housing having one access door (Figures 3 and 4). At the bottom of the housing there was a 5.1 cm (2 in.) diameter drain for condensate from the inside walls. The spiral conveyor, consisting of three 30.3 cm (11-15/16 in.) wide flights, had a 30.5 cm (12 in.) pitch. Steam was distributed through the central tube, which had twelve 1.9 cm (3/4 in.) holes 76.2 cm (30 in.) apart and 7.6 cm (3 in.) above each flight of the spiral conveying surface. The spiral and housing were made of stainless steel (Type 304, No. 2B finish on spiral and No. 3 finish on housing).

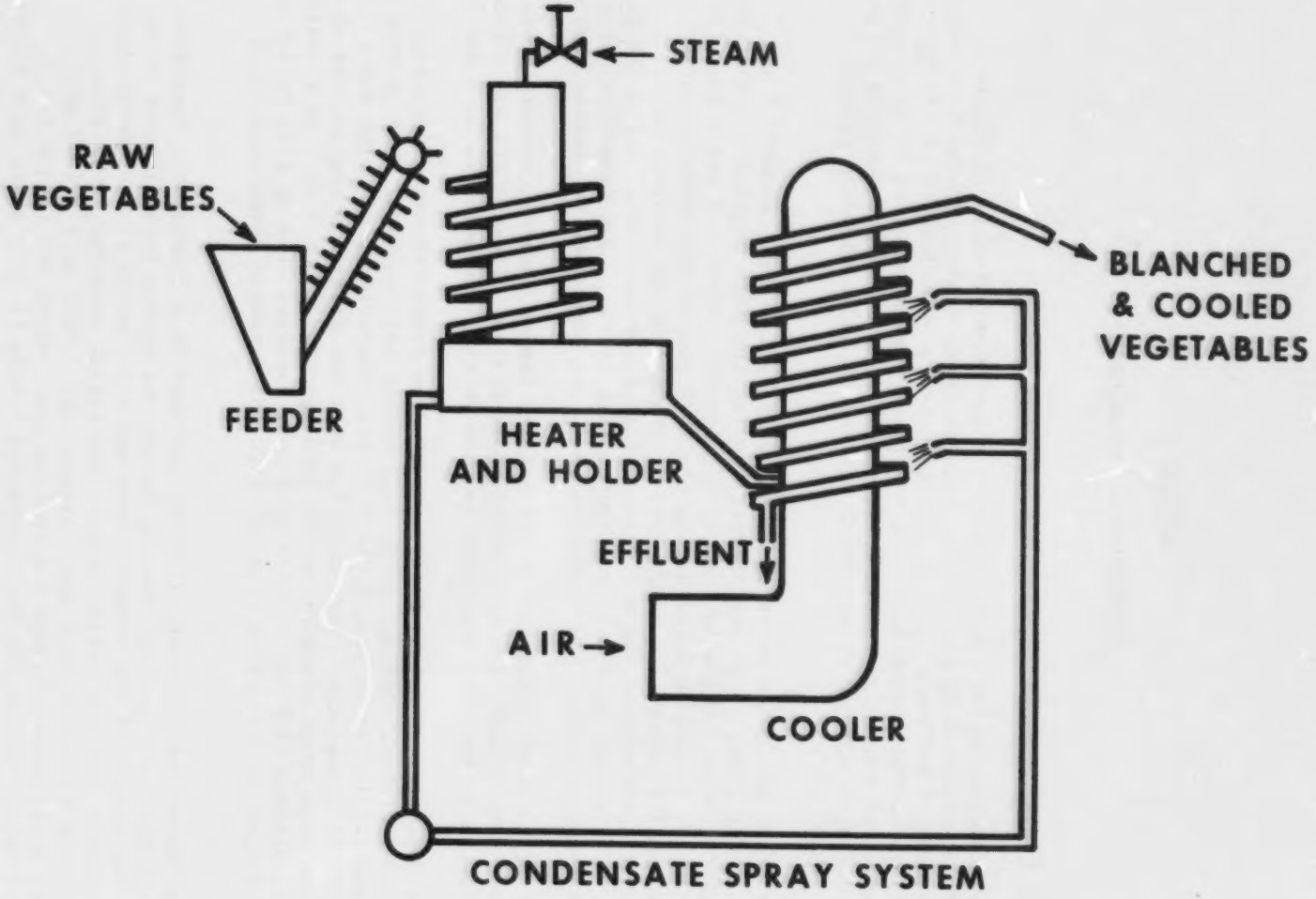

Figure 1. Schematic diagram of vibratory spiral blancher-cooler.

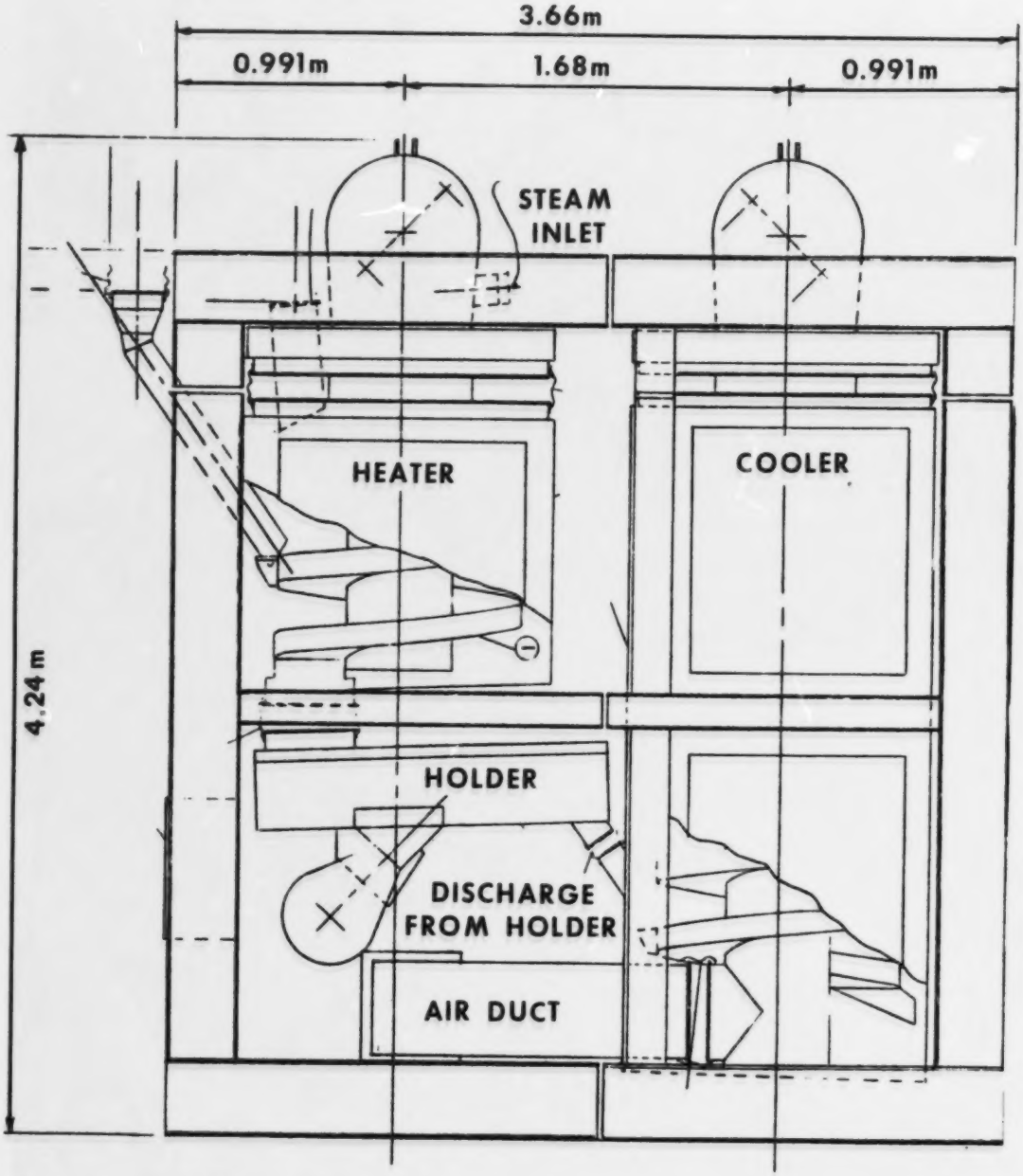

Figure 2. Drawing of vibratory spiral blancher-cooler with cooler in up-flow operation.

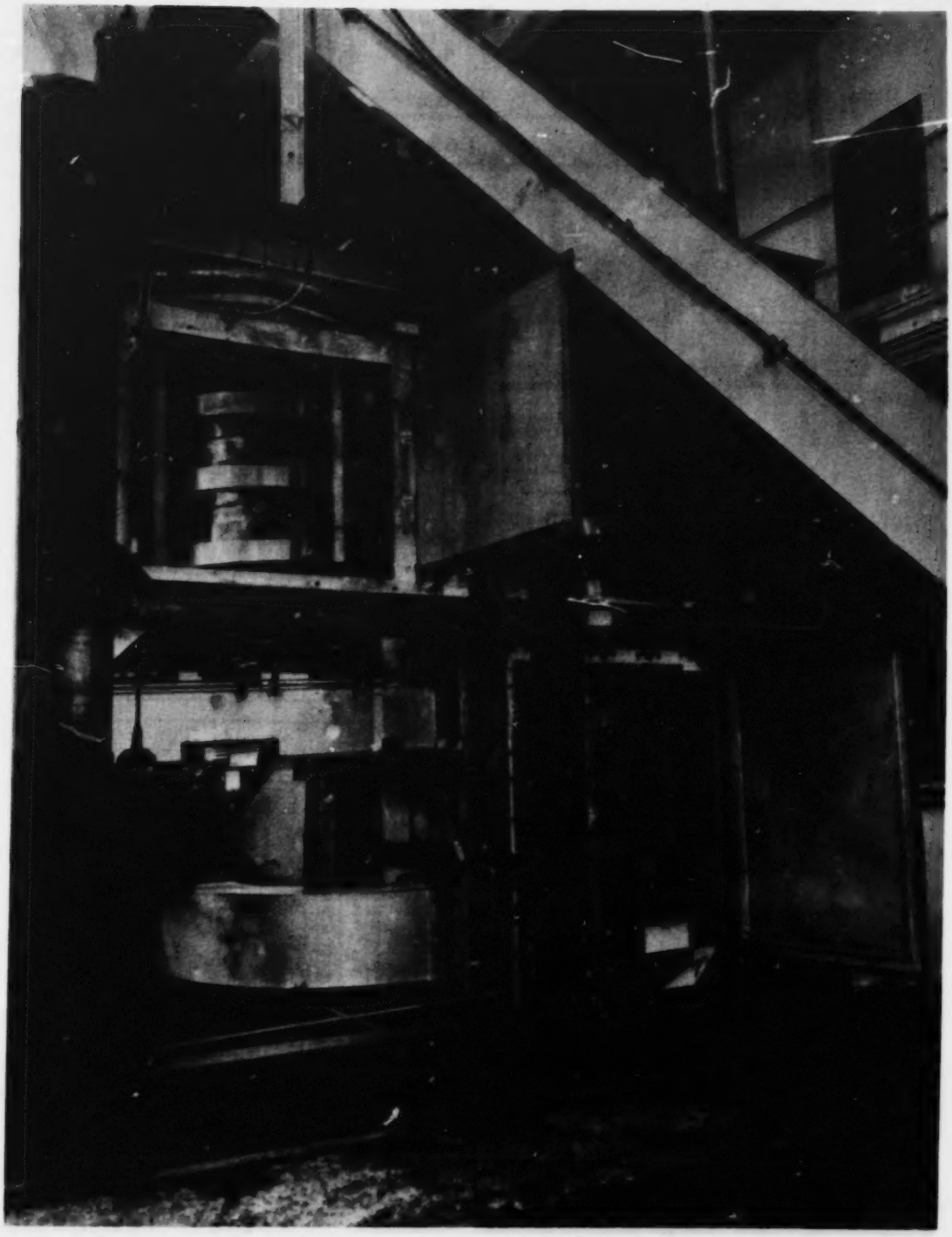

Figure 3. Photograph of vibratory spiral blancher-cooler with cooler in up-flow operation.

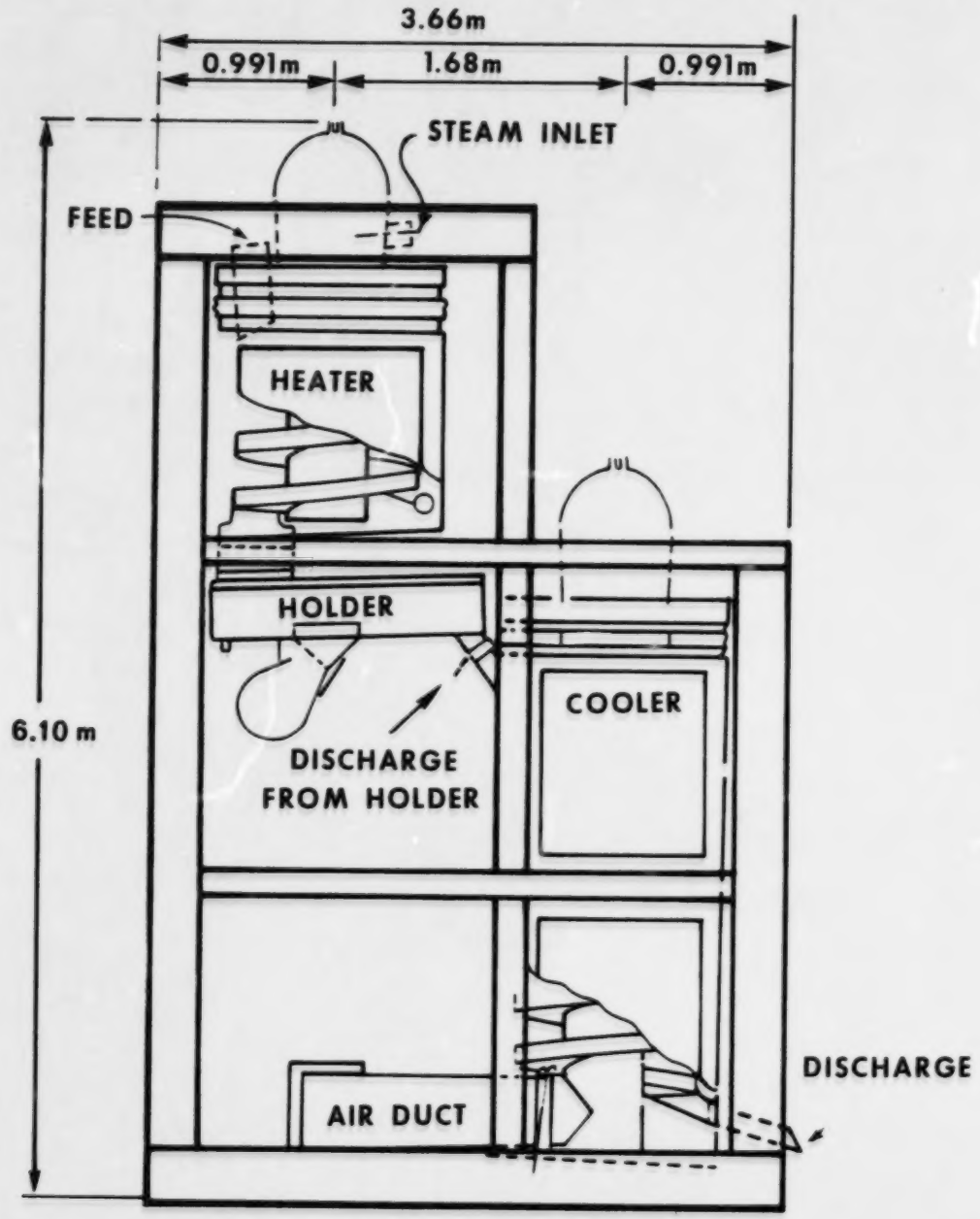

Figure 4. Drawing of vibratory spiral blancher-cooler with cooler in down-flow operation.

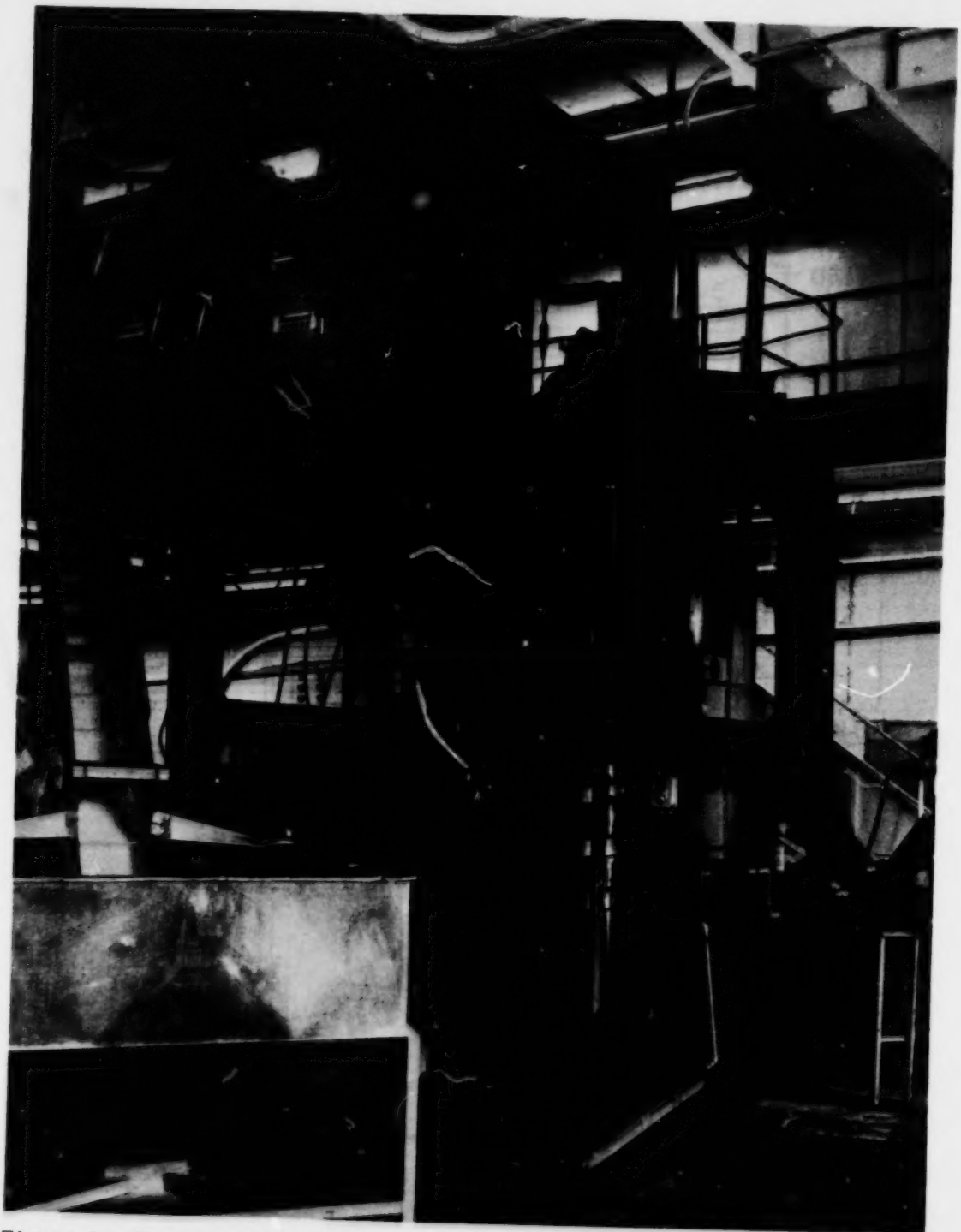

Figure 5. Photograph of vibratory spiral blancher-cooler with cooler in down-flow operation.

There were two feed spouts; one was at the beginning of the top flight and the other was at the beginning of the middle flight. Only the top feed spout was used in the experiments described in this report. Two 1119 W (1-1/2 hp) electrical motors (220 V, 900 rpm), which had eccentric weights on their doubly extended shafts and which were mounted at 45° to the horizontal, vibrated the spiral at a frequency of 890 cpm. The drive motor mounting was suspended by cables and springs to isolate the vibration from the structural framework. The amplitude of vibration could be varied up to 9.5 mm (3/8 in.) in ten steps by shifting the position of the eccentric weights on the motors. The direction of vibration moved the vegetables down the heater spiral, and the amplitude of vibration determined their conveying velocity.

The vegetables leaving the heating spiral dropped into the holder (Figures 2 and 3), which was a horizontally vibrating conveyor 1.5 m long x 0.3 m x 0.3 m (5 ft x 1 ft x 1 ft) enclosed by double wall insulation [2.5 cm (1 in.) air space]. At the bottom of the holder near the feed end there was a 2.5 cm (1 in.) drain for the condensate produced by the vegetables in the heater spiral. A screen (50% open area, 5 mm diam. holes) of perforated stainless steel was installed over the drain to prevent it from being plugged by vegetables. The holder was vibrated at 890 cpm by a 1119W (1-1/2 hp) electrical motor (220 V; 900 rpm) with a doubly extended shaft on which two series of four eccentric weights were mounted. By changing the number of weights, the amplitude of vibration could be varied up to 6.4 mm (1/4 in.). In addition, the holder motor was equipped with a timer that controlled the period the motor was on and off to get a desired residence time. The vibration was isolated from the supporting framework by suspending the holder with cables and springs.

The blanched vegetables leaving the holder were discharged to the cooler, where the vegetables moved up or down the vibrating spiral conveyor, depending on the mode of operation. The cooler spiral conveyor (Figures 4 and 5) had the same design as the one in the heater except that it had 6-1/2 flights. The drive unit for the cooler was of the same design as that in the heater, and by rotating the angle of mounting by 90° the product flow could be changed from up-flow to down-flow. Air was distributed through the central tube over the product through twelve 2.5 cm (1 in.) holes 76.2 cm (30 in.) apart and 8.9 cm (3-1/2 in.) above each flight of the spiral conveying surface. The housing for the cooler was constructed of stainless steel (Type 304, No. 3 finish). It had two access doors, and it had a 5.1 cm (2 in.) drain leading to an effluent collection tank.

The blower (Buffalo Forge, No. 40 MW) used for moving air over the product in the cooler had a rating of 150 m^3/min. (5300 ft^3/min.) of air at 21°C (70°F) and a presure of 15.2 cm (6 in.) of water. A filter (Continental No. 3P439M Side Access Conopac, 90% efficiency) was installed at the inlet of the blower. A damper on the outlet of the blower was used to control the amount of air flow.

The condensate spray system consisted of a pump (Waukesha Sanitary Pump, No. 10, capacity = 11 L/min.), approximately 4.6 m (15 ft) of 2.5 cm (1 in.) diameter stainless steel sanitary pipe and four stainless steel nozzles (Spraying Systems Co., Unijet Nozzle No. 2503). Condensate was sprayed on

the product in the cooler at the first, third, fifth and sixth flights. The condensate from the drain in the holder was filtered either through three layers of cheesecloth or a 100 mesh stainless steel screen to prevent particles from clogging the nozzles.

Temperatures at the inlet and outlet of the heater, holder and cooler were measured by thermocouples and recorded on a multi-point temperature recorder. A water manometer measured the pressure at the blower, and the amount of air flow was determined from the blower performance curve supplied by the blower manufacturer. A rotameter [Fischer-Porter, Model No. 10A1152, 100% of scale = 5.6 m^3/min. (199 scfm) of air], which had been previously calibrated by condensing and weighing the steam flowing through it, was used to measure the flow of steam to the heater. Condensate was removed from the steam supply by passing it through a purifier (V. D. Anderson Co., Model LC-150). A pressure regulator (Spence Engineering Co., 3/4 in. Type ED) maintained a constant pressure at the throttling valve installed in the steam line after the rotameter. The relative humidity of the air at the inlet of the filter on the blower was measured with an electronic humidity indicator (Humi-Check, Beckman Instruments). A hot wire anemometer (Alnor, Thermo-aneomometer) was used to measure the velocity profile of the air over the product in the cooler, and a vane anemometer was used to measure the average air velocity.

Pilot Plant Operating Procedures and Production Line Measurements

Tests on the pilot plant with the cooler in the up-flow mode were conducted with snap bean and lima beans during the fall of 1975. During the summer and fall of 1976, snap beans, lima beans, broccoli, brussels sprouts and cauliflower were tested with the cooler in the down-flow mode.

Raw vegetables for testing the pilot plant were collected into bins 1.2 m x 1.2 m x 1.2 m (4 ft x 4 ft x 4 ft) from the production line at the stage where they were ready for blanching. The snap beans were collected at the point in the production line after they had been washed, sorted and cut. Lima beans were collected after they had been washed and flotation graded in a 13 - 14% brine solution. Because the final rod-reel washers and water-blanchers were so closely connected in the lima bean production line, it was not possible to collect lima beans for the pilot plant runs as throughly cleaned and washed as they were when fed to the production line blanchers. In some cases it was necessary to collect lima beans as they left the brine sorter without any subsequent washing; other times they could be collected after only a brief washing following the brine separator. Brussels sprouts (large size), cauliflower (flowerets), and broccoli (spears) were collected after trimming and cutting, but because of the plant arrangement, it was not possible to collect them after washing.

The testing of the pilot plant consisted of three kinds of experimental runs: preliminary, batch and continuous. Preliminary runs were used to establish the feed rate, blanching and cooling times and to observe the operating characteristics of the pilot plant for each vegetable. Batch runs consisted of blanching and cooling approximately 907 kg (2000 lbs) of

raw vegetables and determining the yield of blanched-cooled vegetables, the solids lost from the raw vegetables and the wasteload. In the continuous runs, the pilot plant was operated for a longer time (2 - 5 hrs) than in the batch runs; the same parameters as in the batch runs were measured, but, in addition, samples were taken for microbiological analysis and sensory evaluation. A labor strike at the plant in the late summer and early fall of the 1976 season allowed only a short time to test brussels sprouts, cauliflower and broccoli; as a result only preliminary runs were possible with these vegetables.

The feed rates, residence times in the heater, holder and cooler, and the flow rates of steam and air were varied in the preliminary runs to determine suitable conditions for processing the vegetables. Velocities on the conveyors were measured by bundling approximately 200 g of vegetables in cheescloth and timing the bundle's passage on the conveyors. With the steam to the heater off, preliminary runs were also used to observe the product flow on all the vibratory conveyors. With the steam to the heater on, the vegetables leaving the cooler were tested for peroxidase (Dietrich and Neumann, 1968), and their temperature was measured. If the peroxidase test was negative and the product temperature was between 27 and 32°C, no further adjustments were made, and a series of batch and continuous runs were begun, using the conditions established in the preliminary runs.

For the batch runs, one bin of raw vegetables was weighed and dumped into the feeder-elevator. After the temperature in the heater reached approximately 100°C (212°F), the vegetables were started through the pilot plant. Samples (150 g) of raw vegetables and of vegetables leaving the cooler were taken every fifteen minutes. The vegetables leaving the cooler were analyzed for peroxidase several times during the run. About every fifteen minutes a 500 g sample of product leaving the cooler was collected into a beaker, and the bulk temperature was measured with a dial thermometer. All the vegetables leaving the cooler were collected from the start of the run to the time when vegetables were no longer being discharged from the holder. The effluent was weighed, and three 500 g samples were taken in polyethylene bottles.

For the continuous runs essentially the same procedure as used in the batch runs was repeated, except that two to four bins (1.8 - 3.6 kkg) of raw vegetables were processed in the pilot plant giving runs from 2 to 5.5 hours. Samples (150 g) of raw vegetables and of cooled vegetables, as well as the temperature of cooled vegetables, were taken every hour. Every hour, samples (50-100 g for total aerobic count and 1.5 kg for sensory evaluation and chemical analyses) were taken of the vegetables leaving the cooler. For quality comparison, 1.5 kg samples of blanched and cooled vegetables from the production line were also taken every hour during the pilot plant run. All vegetable samples were immediately frozen in a -23°C storage room and then later transfered to a -29°C storage room. The frozen 1.5 kg samples were later made into single composites for the production line and for the pilot plant. The blanched and cooled vegetables were collected into bins and weighed. The effluent was collected and weighed. If the run produced more than 40L of effluent, then the effluent was weighed about every hour, and from this quantity a 9 kg composite sample was taken with the remainder

being discarded. From the entire collected effluent or the composite, three 500 g samples were taken in polyethylene bottles.

A series of analyses were done on the samples of the raw vegetables, blanched and cooled vegetables, and effluent. One sample of effluent, taken as described above for each run, was refrigerated at 1°C and a suspended solids (SS) analysis (EPA, 1971) was done within 24 hours; analyses of total solids (TS) and total organic carbon (TOC) (EPA, 1971) were done on this refrigerated sample within a week of the time of the run. Another sample bottle of effluent was frozen, and after about one month it was given to a water analysis laboratory (R. W. Hawksley Co., Richmond, California) for analysis of 5 day biochemical oxygen demand (BOD). A spare sample bottle of effluent was kept frozen for checking any results that were questionable. All vegetable samples were taken in polyethylene bags. The frozen 150 g samples of raw and blanched-cooled vegetables were analyzed for total solids (AOAC, 1965) within two months of the run. The 50-100 g samples taken for total aerobic count were kept at -29°C (for less than one month) until they were analyzed (Sharf, 1966). The vegetable composite samples were also stored at -29°C; within 3 months of the sample collection, part (50-100 g) of the composite was used for analysis of peroxidase, ascorbic acid and chlorophyll conversion (Dietrich and Neumann, 1968) while the remainder was used for sensory evaluation by the Duo-Trio test (ASTM, 1968).

The only effluent and operating condition measurements made on the production line were done on lima bean blanchers and coolers. The blanchers in the lima bean production line were water blanchers of the reel conveyor type. Cooling was done by either a combination of air and flume or only flume. Three sets of measurements were made during a seven hour operating period. The feed rate of vegetables and the effluent discharge rate were measured by collecting and weighing all vegetables going into the blancher and all the effluent leaving the blancher and cooler for short intervals (0.25 or 0.5 min). Samples of raw vegetables (150 g), blanched-cooled vegetables (150 g), and blancher and cooler effluents (500 g) were taken during each measurement. The effluent samples were analyzed for TS, SS, TOC and BOD, and the lima beans samples were analyzed for TS.

Steam flow to a steam blancher on the broccoli production line was measured during each work shift for one week with an orfice meter and a differential pressure recorder (Taylor Instrument Co.). The product flow was determined from the production records for each shift, and an average steam consumption was calculated.

Pilot Plant Operating Conditions

Tables 1, 2 and 3 are lists of the length and type of run, feed rate, blanching time (heating and holding), holder temperatures, steam flow rate and steam consumption, cooling time, cooled vegetable temperature, and the wet-bulb temperature of the cooling air for the different vegetables investigated. The setting of the adjustments on the vibratory conveyors and the

TABLE 1. OPERATING CONDITIONS FOR SNAP BEANS

Run No.+	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp. (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
	Galagreen										
SB-1P	1 in cut	45	1000	0.75	1.1	63-84	170	30	--	--	170
SB-2B	"	50	980	0.75	1.1	85±3	129	32	--	--	130
SB-3B	"	49	960	0.75	1.1	85±6	129	31	--	19	140
SB-4P	"	40	1300	0.75	1.1	85±6	150	38	3.0	18	110
SB-5P	"	52	1100	0.75	1.1	88	177	29±3	3.0	19	160
SB-6B	"	95	1200	0.75	1.1	71-85	161-181	29±2	2.5	18	140-160
SB-7P	"	46	1200	0.75	1.1	88±2	210	30	2.5	--	190
SB-8P	"	33	1600	0.75	1.1	84±4	210-269	33±3	2.5	16	130-170
SB-9P	"	27	2100	0.75	1.1	82±3	269	35	2.5	13	130
SB-10P	"	25	2100	1.3	0.9	86±1	289-309	36	2.5	21	140-150
SB-11P	"	26	2100	1.3	0.9	86±1	309	38	1.9	19	150
SB-12P	"	25	2100	1.3	0.9	85±3	309	36	2.6	18	150
SB-13P	"	26	2000	1.3	0.9	82±3	269-309	34	2.6	23	130-150
	Apennine										
SB-14B	1 in cut	60	1600	1.3	0.9	77±6	249-309	31±1	2.6	18	160-190
	Galagreen										
SB-15B	1 in cut	67	1600	1.3	0.9	86±2	249	37±1	2.6	17	150
	Italian										
SB-16P	Ramones	31	1500	1.2	0.6	85±3	218	37	2.2	17	150
	1 in cut										
SB-17B	"	45	1000	1.2	0.6	91±3	170	28±1	2.2	17	170
SB-18P	"	25	1100	1.2	0.6	91±3	170	33	2.2	18	160
SB-19B	"	44	1100	1.2	0.6	85±3	170	26	2.2	17	160
SB-20B	"	40	1100	1.2	0.6	82±3	170	28	2.2	16	150

(continued)

TABLE 1 (continued)

Run No.+	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
	Galagreen										
SB-21B	1 in cut	57	890	1.2	0.9	86±3	150	28	2.2	16	170
	Italian										
SB-22B	Ramones	41	1200	1.2	0.6	82±3	170	31	2.2	18	140
	1 in cut										
SB-23B	"	41	1200	1.2	0.6	88±3	170	31	2.2	19	150
	Asgrow 274										
SB-24C	1 in cut	190	890	1.1	0.9	84±3	150-129	29±1	2.2	19	170-150
SB-25B	"	60	920	1.1	0.9	86±1	150	29	2.2	17	160
	Yellow Wax										
SB-26P	1 in cut	37	890	1.1	0.9	85±3	150	26	2.2	14	170
	Juliann										
SB-27C	1/2 in cut	161	900	1.1	0.9	87±3	150	28	2.6	16	170
	Apennine										
SB-28C	1/2 in cut	150	980	1.1	0.9	86±4	150	28±1	2.7	17	150
	Apennine										
SB-29B	1 in cut	53	840	1.0	1.0	91±3	150	27	2.5	16	180
SB-30C	"	122	860	1.0	1.1	91±6	150	26	2.5	14	170
SB-31C	1 in cut	125	840	0.5	1.1	91±3	150	25	2.5	13	180
	Yellow Wax										
SB-32B	1 in cut	57	870	0.7	0.75	91±3	150	26	2.5	14	170
SB-33B	"	51	850	0.7	0.75	91±3	150	27	2.5	18	180
	Apennine										
SB-34P	1 in cut	23	800	0.7	0.75	93	150	29	2.3	18	190
SB-35C	"	125	840	0.6	0.7	91±3	150-138	27	2.4	17	180-170

(continued)

TABLE 1 (continued)

Run No.+	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
	Galagreen										
SB-36C	1 in cut	215	880	0.6	0.7	88±3	137	27	2.4	17	160
SB-37C	"	118	860	0.6	0.7	89±3	137	28	2.4	17	160
									Avg. of all runs		160

+P = preliminary run
B = batch run
C = continuous run

TABLE 2. OPERATING CONDITIONS FOR LIMA BEANS

Run No.	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
					Pilot Plant						
LB-1 P	Kingston	45	1300	1.1	1.3	86±2	129	32	--	17	100
LB-2 P	"	Run stopped because cooler was unable to move beans									
LB-3 P	Bridgeton	35	560	1.1	3.5	98	89	24	--	17	160
LB-4 P	"	Run stopped because cooler was unable to move beans									
LB-5 P	"	"	"	"	"	"	"				
LB-6 P	S4	78	540	1.1	1.3	98	89	24±1	--	13	160
LB-7 P	Kingston	83	1200	1.1	1.3	--	102	23	--	12	90
LB-8 B	S4	50	1200	1.1	1.3	91±6	129	27	--	14	110
LB-9 B	Bridgeton	57	1100	1.1	1.3	--	149	25	--	14	130
LB-10 C	"	Run stopped because cooler was unable to move beans									
LB-11 C	Kingston	126	880	1.1	1.3	91±6	110	29±1	--	16	130
LB-12 C	"	149	840	1.1	2.5	92±3	110	28±1	--	16	130
LB-13 C	Bridgeton	272	840	1.1	2.5	93±3	110	28±1	--	16	130
LB-14 C	"	331	700	1.1	2.5	93±2	107	26±2	--	10	150
LB-15 C	Kingston	274	740	1.1	2.5	91±2	109	28±2	1.2	10	150
LB-16 B	"	42	970	0.8	1.9	98	149	26	1.7	14	150
LB-17 C	S4	130	830	0.8	1.9	93	127	24	1.7	13	150
									Avg. of all runs		130

(continued)

TABLE 2. (continued)

Run No. +	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp. (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
					Production Line						
LB PL-1	Kingston	--	4200	4.5*	--	--	--	31	0.9**	--	--
LB PL-2	Kingston	--	3000	4.5*	--	--	--	43	0.3***	--	--
LB PL-3	Kingston	--	5600	4.5*	--	--	--	39	0.9**	--	--

+P = preliminary run
B = batch run
C = continuous run
PL = measurements made on plant production line

*blancher temperature = 99°C
**0.7 min in air with water sprays and 0.2 min in flume
***0.3 min in flume

TABLE 3. OPERATING CONDITIONS FOR BRUSSELS SPROUTS, CAULIFLOWER AND BROCCOLI

Run No.+	Veget. Variety	Run Time (Min)	Feed Rate (kg/hr)	Heating Time (Min)	Holding Time (Min)	Holder Temp (°C)	Steam Flow (kg/hr)	Cooled Veget. Temp (°C)	Cooling Time (Min)	Wet-bulb Temp (°C)	Steam Consumption (kg/kkg)
					Brussels Sprouts						
BS-1 P	large size	55	190	1.8	2.4	99	149	35	—	13	780
BS-2 P	"	60	200	1.8	2.4	98±1	129	35	3	13	630
BS-3 P	"	131	240	1.8	2.4	100	129-90	40±3	3	10	540-370
BS-4 P	"	93	200	1.8	2.4	100	90	32	5	13	430
BS-5 P	"		680	Run stopped because holder overloaded							
					Cauliflower						
C-1 P	flowerets	53	830	1.3	0.6	99	149	21	—	5	180
					Broccoli						
B-1 P	spears	27	96	1.4	1.3	—	90	—	—	--	900
B-2 P	"	40	240	1.2	0.8	99	90	19	5	9	370

+P = preliminary run

air flow rate for each run are shown in the Appendix (Tables A-1, A-2 and A-3). Table 2 also shows the conditions on the lima bean production line at the time of measuring the effluent.

Blanching times (heating plus holding) for each of the vegetables in the initial preliminary runs were set on the basis of the times used on the production line. The division of blanching times into heating and holding times was usually made on the basis of earlier work (Bomben, et al., 1974; Brown, et al., 1974; Lund, 1974). In the case of snap beans, a reduction to the minimum blanching time necessary for adequate blanching in the prototype was measured (Runs SB-35 to 37). Commercial practice in blanching lima beans is usually to blanch beyond the point of enzyme inactivation to attain a softer texture. Commercial blanching times for lima beans may vary between 3.5 to 6.0 minutes; the maximum blanching time possible for lima beans in the prototype was 3.6 minutes. The blanching times achieved with brussels sprouts, cauliflower, and broccoli had to be set less than commercial practice for reasons discussed later in this report.

The heater was maintained at the atmospheric condensing temperature of steam (100°C) by regulating the flow of steam to the heater. The holder temperature was measured by a thermocouple placed at 2/3 of the length of the holder about 4 cm from the bottom. At a given heating and holding time the steam flow was kept at a minumum while maintaining a temperature of 85 to 88°C (185 to 190°F) in the holder.

The vibration amplitude of the cooler was set at the maximum that would give a cooled product temperature of 27 to 32°C (80 to 90°F). The equipment setting to give this condition was established during the preliminary runs. Some difficulty in controlling the residence time was experienced with the up-flow cooler, and this will be discussed later in the report.

SECTION 5

RESULTS AND DISCUSSION

The wasteload produced by the pilot plant as compared to other blanching and cooling techniques was the focus of the project. Effluent was described in terms of hydraulic wasteload and organic wasteload. Hydraulic wasteload is the volume of effluent per unit of raw vegetable (L/kkg), and the organic wasteload is the weight of the BOD, TOC and SS per unit of vegetable processed -- all expressed as kg per 1000 kg of raw vegetables that had been washed, sized, cut and trimmed. In addition to these conventional parameters for describing the wasteload, a material balance on the vegetables passing through the process was performed; the yield described the weight of blanched and cooled vegetable obtained from a given weight of raw vegetable, and the solids loss described the fraction of solids in the raw vegetable lost during blanching and cooling. The Appendix (Table A-4) summarizes the calculations used to obtain the wasteloads and material balances.

Most of the experience gained in operating the pilot plant was obtained with snap beans and lima beans. Because of the limited time available for running brussels sprouts, cauliflower and broccoli, only preliminary runs were possible with these vegetables. During the 1975 season, the cooler operated with product flowing up, and during the 1976 season it operated with product flowing down.

Time limitations in this study precluded a thorough measurement of the effluent produced by the production line. The only effluent data measured on the production line was for lima beans. Although an attempt was made to make measurements on the lima bean production line during normal operating conditions, the fact that the three measurements listed were all taken during one day of plant operation limits their range of applicability. Reliable measurements of the effluent from a blancher or flume in an operating plant requires taking data over a period of time long enough to encompass the range of variations that inevitably occur. Other reports on the measurement of blancher effluent for conventional as well as new blanching techniques (Lund, 1974; Ralls and Mercer, 1974; Bomben, et al., 1975) will be used as a basis for comparison in this report.

Product quality was another consideration in evaluating the operation of this pilot plant. Quality was measured in three ways: (1) total aerobic count, (2) sensory evaluation by the duo-trio test, and (3) chemical analysis of peroxidase, ascorbic acid and chlorophyll conversion.

Economic criteria will eventually determine whether the ideas investigated in this work will be commercially adopted. The economic conditions

of an individual freezing plant are unique because of location, availability of capital, condition of existing blanchers, and other individual economic considerations. The economic calculations that were done for this report simply compared fixed and variable operating costs under what was considered reasonable operating conditions for four alternatives: vibratory spiral blancher-cooler, conventional water blancher, hydrostatic steam blancher, and hot-gas blancher.

Analysis of Prototype Design and Operations

An objective of the experimental runs was to observe how the vibratory conveyors moved the vegetables in the heater, holder, and cooler. Although vibratory conveyors are used in vegetable processing, they have rarely been used to convey vegetables through a blancher (Commercial Mfg. Co., 1975), and this work was the first to use spiral vibratory conveyors for this purpose. Previous work (Brown, et al., 1974) showed that circular vibratory conveyors gave flows approximating plug flow of the vegetables, thereby insuring uniform residence time for the vegetables in a blancher. The spiral conveyors used in the pilot plant gave uniform conveying also as long as their conveying surface was covered with vegetables. Because the blanching was separated into heating and holding steps, any small nonuniformity of heating in the heater spiral was equalized in the holder where vegetables piled up for temperature equilibration and enzyme inactivation.

The design capacity of the pilot plant of 907 kg/hr (1 ton/hr) was calculated assuming a bulk density of 641 kg/m^3 (40 lb/ft^3) and a residence time of 1 min. in the heater, 1 min. in the holder, and 2 min. in the cooler. Since bulk densities can be as small as 400 kg/m^3 (25 lb/ft^3) for broccoli spears and blanching times for large brussels sprouts can be as long as 6 minutes, the actual capacity depended on the vegetable being blanched. In Runs SB-9 to SB-13 the pilot plant far exceeded its design capacity; snap beans, whose bulk density is about 561 kg/m^3 (35 lb/ft^3), were fed to the blancher at over 2000 kg/hr (2.5 tons/hr). Lima beans, whose bulk density is about 641 kg/m^3 (40 lb/ft^3), but required blanching times longer than the 2 minutes used for the design feed rate, also exceeded the design capacity in some runs (LB-1, 7, 8, 9, and 16). Brussels sprouts, cauliflower, and broccoli, all of which have lower bulk densities and longer blanching times than those used for designing the conveyors, had feed rates below the design capacity. The actual capacity of the pilot plant for these latter vegetables could not be accurately established for reasons mentioned later in this report.

The blanching times for snap beans in the pilot plant (heating and holding) sufficient to produce a negative peroxidase were generally less than those on the production line. These shorter blanching times were achieved because the pilot plant had sealed ends, thus insuring that the heater was maintained at 100°C, and because the heating and holding sections assured a uniform temperature among the individual pieces leaving the holder. Steam blanchers with unsealed ends, such as the one used for steam flow measurements on the production line, may have a considerable variation in temperature along their length because of air entering through the feed and

discharge ends. In addition, the belt in a conventional steam blancher is often heavily loaded, which causes the vegetables within a blancher to experience a different temperature treatment.

The holder was not large enough to provide adequate capacity for brussels sprouts. At the feed rates shown in Table 3 for Runs BS-1 to BS-4, the heater was not fully loaded giving some nonuniformity in blanching times. In Run BS-5, when a more fully loaded heater was tried, the holder became overloaded. The blanching time of 4.2 minutes (1.8 minutes heating + 2.4 minutes holding) was the maximum possible in the pilot plant. Although the brussels sprouts processed in these experiments showed negative peroxidase tests, the exact time of blanching was uncertain because of the underloaded heater and the very slow conveying velocity in the holder (10 sec. on; 40 sec. off). To provide proper conditions for blanching brussels sprouts, the size of the holder would need to be increased sufficiently to accomodate a fully loaded heating spiral.

Broccoli spears tended to bridge and block the 15 cm x 23 cm (6 in. x 9 in.) entrances and exits of the heating and cooling spirals if the feed rate was above 240 kg/hr. Thus again the heater spiral could not be loaded at its full capacity. For unobstructed flow of broccoli through the prototype, these entrances and exits would have to be enlarged. The blanching time of 3.5 minutes used on the broccoli production line could not be achieved in the prototype because the holder could not convey broccoli at the heavy loading required to attain a long residence time in the holder. At the low vibration amplitude (0.32 cm) and the long time off (40 sec.) the heavily loaded holder conveyor could not move the broccoli. At higher vibration amplitudes (0.64 cm or larger) or lighter loadings (on continuously) the broccoli could be moved by the conveyor, but of course these conditions gave a shorter holding time. Adequate holding time with broccoli would be possible with a longer holder.

Cauliflower moved uniformly and without difficulty through all conveyors in the pilot plant. However, to use the spiral conveyors at full capacity and to provide for a longer holding time (conventional blanching times = 3.5 min.), a larger holder would be necessary.

Because of the equipment limitations mentioned above, the capacity of the pilot plant for brussels sprouts, cauliflower and broccoli could not be determined in these tests. The tests did establish that the vibratory conveyors could move these vegetables and that adequate blanching and cooling could be achieved in the prototype; however, establishing the exact sizes of the holder and feed and discharge openings needed so that the prototype could handle these vegetables continuously and reliably would require further testing.

Table 1 shows that in those runs with snap beans where the feed rate exceeded the design capacity, the cooled vegetable temperatures exceeded 27°C (80°F), which was the design product temperature. In the snap bean and lima bean runs done at the design capacity, the cooled product temperature was generally at or below 27°C. The actual temperature in any given run was dependent on the wet-bulb temperature of the ambient air. The low

temperatures achieved with cauliflower and broccoli were the result of the low conveyor loadings and the very low wet-bulb temperatures of the ambient air. Figure 6 shows the results of measurements of air velocities as a function of distance above a conveyor flight. It clearly shows that most of the air was not being aimed at the product. This condition gave adequate cooling when the pilot plant was operated at its design capacity since only a single layer of product was on the cooler conveyor; whereas at the higher feed rates tried in Runs SB-9 to SB-13, the cooler conveyor had multiple layers of product. An air distribution system, which aimed the air directly at the product, would give more air flow over the product and thereby increase the rate of cooling and give a higher cooler capacity. Air could be directed at the product by using slotted tubes extending from the existing air holes out to the edge of the flights.

The cooler was operated with product flowing upward during the 1975 season and downward during the 1976 season. The cooler operated satisfactorily with snap beans in either mode of operation (Runs SB-1 to SB-3 were up-flow), but it had more capacity in down-flow operation. The cooler could move lima beans upward, but the flow was erratic, and sometimes the lima beans could not be moved at all by the conveyor. This problem was intermittent, and no single cause for its occurence was determined although the following characteristics were observed: (1) The longer the lima beans were blanched, the more slowly they tended to move on the conveyor. (2) Stems, pods, and undersize beans collected on the surface of the cooler conveyor. (3) If during a run the lima beans stopped moving in the cooler and then the cooler was washed down with water, the cooler could again convey the lima beans. Despite these problems the cooler in up-flow was operated continuously with lima beans without washing for over five hours (Run LB-14). None of these problems were encountered when cooling lima beans in the down-flow mode (Runs LB-16 and -17).

The cooler could not continuously convey upward blanched brussels sprouts, blanched cauliflower or blanched broccoli; it was able to convey upward raw brussels sprouts and raw broccoli but not raw cauliflower. Changing the angle of vibration from 45° to 30° from the horizontal did not make these vegetables move up the cooler. The cooler had no difficulty in conveying any of these vegetables downward. From the standpoint of design, the only disadvantage of not being able to convey upward in the cooling spiral is some loss in compactness since the overall height of the equipment must be higher for down-flow (Figure 2 and 4).

The cleaning of the pilot plant was easily accomplished after every run. The smooth stainless steel surfaces of the conveyors were easily cleaned with cold water, and the spray system could easily be flushed with detergent. Clean-in-place equipment would appear to be easily incorporated in the design. Microbiological assays of vegetables leaving the cooler, described later in this report, show that the sanitation of the design is well within accepted limits.

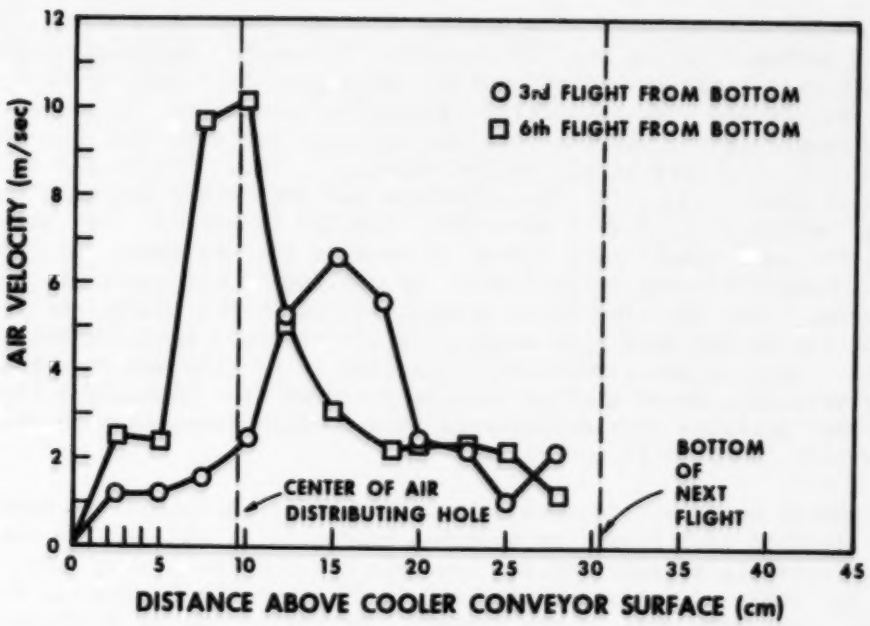

Figure 6. Air velocity distribution over cooler spiral conveyor.

Material Balances and Wasteload

Tables 4, 5, and 6 show the characteristics of the liquid effluent from the pilot plant and the results of a material balance on the different vegetables entering and leaving the pilot plant for each of the runs. In the case of lima beans, the three measurements made on the production line are also shown in Table 5. The Appendix (Tables 5, 6 and 7) gives the results of the wastewater analyses for each of the runs. A total volume of effluent of less than 0.5 liter collected during a run was considered negligible, and this small amount of effluent is indicated by hydraulic loads preceeded by a "less than" sign (<). Table 7 shows the means of the values in Table 4, 5, and 6 grouped by vegetable variety. When there were a sufficient number of runs to make it applicable, a 95% confidence limit was calculated.

The variations in hydraulic wasteload and organic wasteload for a given vegetable appeared to be primarily because of variations in the raw vegetable variety and maturity. Table 7 indicates that for snap beans the variety made a significant difference in the wasteload. Within a given variety of snap beans (Tables 1, 4 & 7) the variations in wasteload are not large with the exception of Run SB-12, which was a short duration preliminary run. On the other hand, lima beans showed no distinguishable correlation between variety and wasteload. Lima beans did however have large variations in wasteload among runs of a given variety (Tables 2, 5 and 7). Comparisons between Runs LB-15 (36.09% total solids, Kingston variety) and LB-16 (38.70% total solids, Kingston variety) and LB-13 (41.6% total solids, Bridgeton variety) and LB-14 (35.92% total solids, Bridgeton variety) indicated that lima beans with higher solids content produced less wasteload. One would expect that a lower volume of effluent would be produced during the blanching of a drier or more mature (higher solids content) raw vegetable [Lund (1974) and Bomben, et al. (1973)]. There were not enough runs done with brussels sprouts, cauliflower or broccoli to make observations about variations in wasteload.

The material balances calculated in Tables 4, 5, 6 and 7 were done to trace the loss of solids and weight during blanching and cooling. Bomben, et al. (1975) demonstrated that different methods of cooling led to differences in yield and solids loss. The yield is important in vegetable freezing since frozen vegetables are sold by weight. Air cooling obviously reduces the hydraulic load as compared to flume cooling, but at the expense of a lower vegetable yield. Yields of greater than 100% are possible since the vegetables can absorb more liquid in cooling than was lost in blanching. Solids loss is a measure of the nutrients that are leached from a vegetable as it is blanched and cooled. Measurements on the production line were made only for lima beans, but it was not possible to measure accurately the yield, so that solids loss is the only material balance comparison possible between commercial processing and the pilot plant. Table 7 clearly shows for lima beans the advantages in solids retention and wasteload reduction possible with the pilot plant as compared to the production line.

TABLE 4. YIELD, SOLIDS LOSS & LIQUID WASTELOAD FOR SNAP BEANS

Run No.	Yield (%)	Solids Loss (%)	Hydraulic Load (L/kkg)	BOD (kg/kkg)	TOC (kg/kkg)	SS (kg/kkg)
SB-1 P	86.5	--	51	0.80	0.62	--
SB-2 P	98.5	0.71	32	0.52	0.31	0.037
SB-3 P	97.2	0.68	29	0.44	0.29	0.044
SB-4 P	96.7	0.62	33	--	0.28	--
SB-5 P	99.4	--	--	--	--	--
SB-6 B	96.4	0.18	5.7	--	0.06	--
SB-7 P	99.7	--	8.5	--	--	--
SB-8 P	98.7	0.76	23	--	0.29	--
SB-9 P	98.5	1.1	38	--	0.43	--
SB-10 P	95.6	0.50	15	--	0.22	--
SB-11 P	100	2.2	79	--	0.95	--
SB-12 P	96.3		<0.6	--	--	--
SB-13 P	96.0	0.21	7.6	--	0.11	0.043
SB-14 B	102		<0.3	--	--	--
SB-15 B	98.7	1.2	35	--	0.42	0.14
SB-16 P	98.5	1.0	43	--	0.46	0.16
SB-17 B	102	--	<0.6	--	--	--
SB-18 P	99.5	--	<0.6	--	--	--
SB-19 B	99.1	--	<0.6	--	--	--
SB-20 B	99.1	--	<0.6	--	--	--
SB-21 B	96.8	1.4	34	--	0.49	0.15
SB-22 B	96.1	--	<0.6	--	--	--
SB-23 B	101.6	--	<0.6	--	--	--
SB-24 C	98.8	1.9	47	0.89	0.63	0.20
SB-25 B	95.1	0.85	27	--	0.29	0.090
SB-26 P	99.8	0.29	13	--	0.13	0.041
SB-27 C	96.4	0.94	23	0.59	0.36	0.11
SB-28 C	95.8	1.6	41	0.90	0.52	0.14
SB-29 B	95.5	1.4	39	--	0.49	0.13
SB-30 C	98.2	1.3	34	0.85	0.50	0.14
SB-31 C	95.8	1.8	53	0.98	0.59	0.20
SB-32 B	94.1	1.7	58	--	0.52	0.15
SB-33 B	94.9	1.7	61	--	0.50	0.16
SB-34 P	90.6	1.6	60	--	--	--
SB-35 C	98.6	1.4	51	1.2	0.56	0.15
SB-36 C	99.4	0.41	13	0.34	0.18	0.057
SB-37 C	98.8	0.89	27	0.57	0.37	0.12

TABLE 5. YIELD, SOLIDS LOSS & LIQUID WASTELOAD FOR LIMA BEANS

Run No.	Yield (%)	Solids Loss (%)	Hydraulic Load (L/kkg)	BOD (kg/kkg)	TOC (kg/kkg)	SS (kg/kkg)
			Pilot Plant			
LB-1 P	89.2	0.70	47	0.89	0.67	0.50
LB-2 P	Run stopped because cooler was unable to move beans					
LB-3 P	83.2	--	42	0.65	0.58	0.22
LB-4 P	Run stopped because cooler was unable to move beans					
LB-5 P	" " "			" "	" "	
LB-6 P	90.9	--	39	0.77	0.54	0.42
LB-7 P	94.1	0.49	28	0.83	0.51	0.40
LB-8 B	92.1	0.052	4.6	0.098	0.064	0.041
LB-9 B	--	0.15	7.9	--	0.16	0.14
LB-10 C	Run stopped because cooler was unable to move beans					
LB-11 C	--	0.20	11	--	0.20	0.17
LB-12 C	93.2	0.37	20	--	0.39	0.35
LB-13 C	92.9	0.15	8.2	0.24	0.15	0.12
LB-14 C	92.1	0.79	40	0.79	0.99	--
LB-15 C	92.0	1.2	60	1.9	1.5	1.8
LB-16 B	83.9	--	<0.7	--	--	--
LB-17 C	90.8	--	10	--	--	--
			Production Line			
LB PL-1						
blanching	*	1.7	550	3.2	1.8	0.85
cooling		0.52	530	0.91	0.38	0.15
LB PL-2						
blanching		1.6	460	3.8	1.7	0.85
cooling		1.2	780	1.0	0.41	0.15
LB PL-3						
blanching		1.6	370	3.2	1.8	0.68
cooling		0.48	310	1.0	0.44	0.12

*Yield could not be accurately measured on the production line.

TABLE 6. YIELD, SOLIDS LOSS AND LIQUID WASTELOAD FOR BRUSSELS SPROUTS, CAULIFLOWER AND BROCCOLI

Run No.	Yield (%)	Solids Loss (%)	Hydraulic Load (L/kkg)	BOD (kg/kkg)	TOC (kg/kkg)	SS (kg/kkg)
			Brussels Sprouts			
BS-1 P	102	—	<3	—	—	—
BS-2 P	—	—	<3	—	—	—
BS-3 P	88.7	0.29	15	0.27	0.15	0.052
BS-4 P	94.4	0.65	41	0.59	0.31	0.093
BS-5 P	Run stopped					
			Cauliflower			
C-1 P	97.2	—	<3	—	—	—
			Broccoli			
B-1 P	—	—	<11	—	—	—
B-2 P	103	0.33	11	0.25	0.15	0.091

Product Quality

Table 8 shows the results of the total aerobic counts done on vegetables leaving the cooler. The counts on all the lima bean samples taken from the pilot plant were much lower than those of product taken from the production line, and these counts were far below the acceptable 10^5 colonies/g indicated by Sharf (1966). In most of the runs with snap beans the counts on the cooled vegetables from the pilot plant were much higher than the production line (Run No. SB-24 to -36). These runs were all done with the product flowing downward in the cooler, and an inclined belt had to be used to elevate the cooled vegetables from the exit of the cooler to a collection bin (Figure 5). In runs SB-24 to -36, samples were taken from the vegetables leaving the inclined belt elevator; however in Run SB-37, samples were taken directly from the exit of the spiral cooler, and the counts obtained on those samples were much lower than those of previous runs and about the same as the production line. Runs LB-11 to LB-15 were done with product flowing upward in the cooler, and thus did not require an inclined-belt elevator. Samples for LB-17, BS-3, BS-4 and C-1 were also taken directly from the exit of the down flow cooler. The high counts when using the inclined belt elevator dramatically point out the difficulty in keeping belt conveyors clean as opposed to vibratory spiral conveyors. In all cases where vegetables were taken directly from the spiral conveyors, the counts were lower than, or about the same as, the counts of vegetables taken from the production line; furthermore, the counts on the vegetables from the pilot plant showed

TABLE 7. MEANS OF YIELDS, SOLIDS LOSSES AND LIQUID WASTELOADS WITH 95% CONFIDENCE LIMITS

	Yield (%)	Solids Loss (%)	Hydraulic Load (L/kkg)	BOD (kg/kkg)	TOC (kg/kkg)	SS (kg/kkg)
Snap Beans						
Galagreen	97.2±0.4	0.83±0.09	27.0±2.6	0.53±0.10	0.36±0.03	0.084±0.017
Apennine	96.6±1.2	1.51±0.07	39.8±6.8	0.98±0.12	0.53±0.02	0.15 ±0.02
Ramones	99.4±0.7	not enough effluent for sample				
Lima Beans						
Kingston	90.5±2.3	0.50±0.18	27.9±9.6	0.90±0.61	0.55±0.23	0.54 ±0.28
Bridgeton	89.4±7.7	0.37±0.53	24 ± 15	0.56±0.42	0.47±0.32	0.16± 0.07
S-4	91.3±1.0	0.052	18 ± 27	0.44	0.30	0.23
Production Line						
blanching-	*	1.64±0.06	460 ± 130	3.37±0.49	1.74±0.07	0.79±0.14
cooling-		0.73±0.58	540 ± 340	0.98±0.09	0.41±0.04	0.14±0.02
blanching + cooling		2.37	1000	4.35	2.15	0.93
Brussels Sprouts	95.0±9.6	0.47	15 ± 14	0.43	0.23	0.073
Cauliflower	97.2	—	3	—	—	—
Broccoli	103	0.33	11	0.25	0.15	0.091

*Yield could not be accurately measured on the production line.

TABLE 8. TOTAL AEROBIC PLATE COUNTS ON VEGETABLES LEAVING COOLER

(Colonies/g)

	Hours After Start of Run					Production Line
	1	2	3	4	5	
Snap Beans						
SB-24	7.9×10^4	3.5×10^4	3.2×10^4			30
SB-27	6.4×10^5	9.8×10^4	1.3×10^5			--
SB-28	1.5×10^5	1.4×10^5	1.0×10^5			20
SB-30	9.2×10^4	1.0×10^5				1.0×10^2
SB-31	1.9×10^5	1.6×10^5				6.2×10^3
SB-35	4.8×10^5	4.3×10^5				3.7×10^2
SB-36	9.2×10^5	2.9×10^5	2.2×10^5	6.0×10^5		2.1×10^2
SB-37	1.2×10^3	6.1×10^2				7.0×10^2
Lima Beans						
LB-11	2.0×10^3	1.5×10^3				7.2×10^4
LB-12	7.0×10^2	7.5×10^2	4.6×10^2			
LB-13	1.2×10^3	8.3×10^2	5.8×10^2			
LB-14	5.1×10^2	7.0×10^2	1.3×10^3	2.0×10^3	1.1×10^3	
LB-15	7.3×10^2	5.0×10^2	5.0×10^2	5.0×10^2		
LB-17	3.8×10^4	4.3×10^4				1.5×10^6
Brussels Sprouts						
BS-3	1.4×10^4	2.0×10^3				1.4×10^5
BS-4	3.8×10^5	1.7×10^5				1.1×10^5
Cauliflower						
C-1	4.9×10^4					

no tendency to increase with time, as demonstrated by Run LB-14, which continued for over five hours.

Table 9 gives the results of sensory comparisons (duo-trio) of product from the pilot plant with that from the production line. The results are reported as the number of judgements correctly identifying the sample that was identical to the control (% correct). The control for a comparison was either the pilot plant or production line sample. Judges were also asked to state which sample they preferred. Probabilities are from the Binomial Probability Table.

TABLE 9. SENSORY EVALUATION OF SNAP BEANS AND LIMA BEANS BY DUO-TRIO TEST

Run Number	Total Number of Judgments	% Correct	% Preference for Pilot Plant Sample
		SNAP BEANS	
SB-1	36	61	42
SB-2	36	61	44
SB-3	34	53	68
SB-28	40	68*	65*
SB-36	40	78**	58
		LIMA BEANS	
LB-7	41	66*	54
LB-8	40	65*	67*
LB-9	41	80**	63
LB-10	38	63	32*
LB-11	40	63	55

*Probability < 0.05
**Probability < 0.01

The sensory evaluation showed that in some cases a significant difference could be detected in the taste or texture of the product because of processing in the pilot plant as compared to processing in the production line. In those cases of snap beans where significant differences could be detected, the judges, citing better flavor or texture, preferred the sample from the pilot plant. This better flavor or texture could have been either the result of the shorter blanching times or less loss of solids in the pilot plant as compared to the production line. In the case of lima beans, the preferences of the panel were not as consistent, and in one case (LB-10) the panel preferred lima beans taken from the production line. Some of the differences found by the judges in the lima bean samples probably came from

the fact that the lima beans for the pilot plant could not be collected after the final wash prior to blanching, and thus contained more of the salt absorbed in the flotation grader. In general it appears safe to conclude that the pilot plant had no adverse affect on the taste, texture or appearance of vegetables, and in some cases, it improved the flavor and texture.

Table 10 gives the results of the analyses for total solids, peroxidase, ascorbic acid and chlorophyll conversion of pilot plant and production line samples. The numbers are averages of two or three analyses done on 50 to 100 g of vegetables. Ascorbic acid is reported without accounting for differences in moisture between the frozen vegetables from the production line and those from the pilot plant.

The results of peroxidase test are reported in two ways. In those cases where a raw vegetable sample was available at the time of analysis, a residual peroxidase was determined; otherwise the time for a color change in the test solution is reported. For the conditions used in this test, adequate blanching was shown by less than 6% residual peroxidase or no color change in more than 210 sec. Except for one sample of brussels sprouts taken from the production line (BS-3), all samples shown in Table 10 were adequately blanched. Lima beans are commonly blanched longer than necessary for peroxidase inactivation, the criterion being texture instead. Since in most cases the pilot plant used shorter blanching times, the peroxidase contents of vegetables that were processed in it were higher, but in no case did the pilot plant not blanch sufficiently. In one of the runs with brussels sprouts (BS-4), the pilot plant vegetables were seriously overblanched because of the difficulties, described earlier, in maintaining constant holding times with the holder operating at a very slow conveying velocity.

Generally, the ascorbic acid content of the vegetables processed in the pilot plant was higher than that of the vegetables taken from the production line (Table 10). Some of these differences can be accounted for by differences in total solids between the samples, but in some cases (SB-2, -3, -28, -36) the vegetables processed in the pilot plant did indeed have more retention of ascorbic acid. This retention could have been the result of both shorter blanching times and less leaching.

Ascorbic acid is lost both by leaching and thermal degradation, but an increase in chlorophyll conversion is solely a measure of thermal degradation. As explained previously, the conveying velocity in the lima bean runs with product flowing upward in the cooler was sometimes slow and erratic, and the heavily loaded conveyor gave an excessively slow cooling rate. This slower cooling rate caused higher chlorophyll conversions than those on the production line (Table 10, runs LB-12, 13, 14, and 15). In those lima bean runs with up-flow where the cooler had shorter residence times and less loading (LB-8 and -11) and the down-flow run (LB-17), no substantial differences between chlorophyll conversions in the prototype and production line samples appeared. The prototype samples of snap beans, in either up-flow or down-flow, had lower chlorophyll conversions than did the production line samples, indicating that the prototype, when operating

TABLE 10. CHEMICAL ANALYSES OF VEGETABLES

Run No.	Raw TS (%)	Blanch & Cool TS Pilot Plant (%)	Blanch & Cool TS Prod. Line (%)	Pilot Plant Yield (%)	Pilot Plant Solids Loss (%)	Residual Peroxidase Pilot Plant (%)	Residual Peroxidase Prod. Line (%)	Ascorbic* Acid Pilot Plant (mg/100 g)	Ascorbic* Acid Prod. Line (mg/100 g)	Chlorophyll Conversion Pilot Plant (%)	Chlorophyll Conversion Prod. Line (%)
					SNAP BEANS						
SB-1	10.76	11.20	10.35	86.5	--	2.1	1.6	14.1	13.9	16.8	16.8
SB-2	10.75	10.75	--	98.5	0.708	1.1	0.5	15.1	13.4	13.8	14.1
SB-3	10.75	10.40	--	97.2	0.707	1.5	0.5	14.1	13.4	13.8	14.1
SB-28	9.35	9.09	--	99.4	1.56	402sec**	595sec**	11.7	9.8	18.2	--
SB-36	10.97	10.23	--	99.4	0.412	300sec**	800sec**	14.0	11.8	11.9	--
					LIMA BEANS						
LB-8	40.65	41.71	34.60	92.1	0.052	0.0	0.0	18.7	16.7	13.0	14.5
LB-11	40.86	39.74	36.49	--	0.202	0.0	0.0	26.7	23.8	11.9	13.9
LB-12	40.72	40.13	36.01	93.2	0.372	0.0	0.0	27.2	24.0	17.2	10.8
LB-13	41.60	40.71	38.03	92.9	0.148	0.0	0.0	20.6	19.7	15.6	13.0
LB-14	35.92	35.62	34.80	92.1	0.794	0.0	0.0	19.1	20.3	19.1	11.3
LB-15	36.09	36.07	34.82	92.0	1.22	0.0	0.0	24.6	25.7	18.9	8.0
LB-17	41.82	39.29	--	90.8	--	>1500sec**	>1500sec**	23.7	7.0***	13.5	55.2***
					BRUSSELS SPROUTS						
BS-3	13.91	13.42	--	88.7	0.293	330sec**	110sec**	62.0	69.6	.6	37.2
BS-4	13.15	12.42	--	94.4	0.645	1000sec**	290sec**	75.5	66.0	5.6	43.8

*Ascorbic acid analyses were not corrected for differences in the amount of water in the vegetables.
**Time for color change in peroxidose test; no color change in > 210 sec or < 6% residual peroxidase indicates adequate blanching.
***Sample may have been left at room temperature too long before freezing.

properly, could rapidly blanch and cool vegetables. The high chlorophyll conversion shown for brussels sprouts in Run BS-4 resulted from the conditions of overblanching discussed earlier.

Effluent Generation and Steam Consumption of Blanchers

Table 11 compares the wastewater produced by various blanching techniques. The data reported by Bomben, et al. (1975) was from small scale tests, and included cooling. The data reported by Lund (1974) and Ralls and Mercer (1974) was taken either in pilot plants or commercial production line blanchers, and they do not include cooling.

The organic wasteload for snap beans and lima beans from the spiral vibratory blancher-cooler was essentially the same as that found by Bomben, et al. (1975) in their small scale tests of conventional steam blanching and air cooling with condensate spray. The hydraulic load from the vibratory blancher-cooler pilot plant was less than that from the small scale tests done by Bomben, et al. (1975) probably because the pilot plant used a larger ratio of air to vegetables and thus had more evaporation during cooling.

The results of other work done on a pilot plant or production line scale shown in Table 11 do not include the wasteload from cooling, and therefore they cannot be directly compared to the results of this work. Except for hot-gas blanching, the vibratory spiral blancher-cooler generally produced about the same or less organic wasteload for both blanching and cooling than did the others for blanching alone. It should also be noted that in the case of snap beans, the work cited here (Lund, 1974; Ralls and Mercer, 1974) was blanching for canning, and thus the beans were heated to lower temperatures; a lower product temperature probably produced less wasteload.

Since blanching is the major source of organic wasteload in most vegetable processing plants (Ralls and Mercer, 1973), reduction or elimination of its wasteload will have a major effect on the plant effluent. Even though it eliminates effluent completely for snap beans, hot-gas blanching does not do this for all vegetables (Ralls and Mercer, 1974). In addition this technique is dependent on increasingly scarce natural gas as a heat source, which will probably preclude its being used commercially. The small hydraulic load from the vibratory spiral blancher-cooler would significantly reduce the volume of plant wastewater that had to be treated.

Table 12 gives the steam use for various blanching systems. The calculations for the theoretical steam requirement and for the steam equivalence of hot-gas blanching are shown in the Appendix (Table A-8). The vibratory spiral blancher-cooler has the highest steam efficiency, thereby showing the effectiveness of its seals against steam leakage and its double wall insulation. The low efficiency of conventional steam blanchers is readily apparent, and even with the newly designed hydrostatic steam blanchers, the efficiency is low as compared to the vibratory spiral blancher-cooler. Although the hot-gas blanching pilot plant has a higher efficiency than

TABLE 11. WASTELOAD PRODUCED BY DIFFERENT BLANCHING TECHNIQUES

Blanching Technique	Hydraulic Load (L/kkg)	Organic Load BOD (kg/kkg)	Organic Load TOC (kg/kkg)	Organic Load SS (kg/kkg)
Vibratory Spiral Blancher-Cooler*				
Snap beans (Galagreen)	27	0.53	0.36	0.084
Lima beans (Kingston)	28	0.90	0.55	0.54
Water Blanching with Air/Water Spray Cooling*				
Lima beans (Kingston)	1000	--	2.15	0.93
Steam Blanching and Air Cooling with Cond. Spray+				
Snap beans (Galagreen)	50	--	0.37	--
Lima beans (Kingston)	40	--	0.60	--
Steam Blanching and Water Cooling+				
Snap beans (Galagreen)	5100	--	1.5	--
Lima beans (Kingston)	5100	--	2.8	--
Steam Blanching without Cooling**				
Snap beans	120	0.55	--	0.02
Lima beans	240	3.5	--	--
Water Blanching without Cooling				
Snap beans++	600	3.2	--	0.61
Snap beans**	340	--	--	--
Lima beans**	820	0.65	--	--
Hot-Gas Blanching without Cooling++				
Snap beans	0.06	< 0.01	--	< 0.01

*This work
+Bomben, et al. (1975)
**Lund (1974)
++Ralls and Mercer (1974)

TABLE 12. ENERGY USE IN BLANCHING

Blanching Technique	Steam Requirement (kg/kkg)	Efficiency (%)
Theoretical*	134	100
Vibratory Blancher-Cooler**	158	85
Conventional Steam** Blancher	2580	5
Hydrostatic Steam+ Blancher	500	27
Hot-Gas Blanching* (steam equivalent)	240	56
Conventional Water Blancher++	--	60

*See Appendix, Table A-8
**This work
+Ray (1975) and Layhee (1975)
++Estimated using information given by Lazar and Rasmussen (1964)

commercial steam blanchers, its efficiency is substantially lower than that of the vibratory spiral blancher-cooler. No measurement of the steam consumption of the water blanchers in the production line was made, nor was it possible to find any steam consumption measurements for water blanchers reported in the literature. The efficiency reported in Table 12 for water blanchers was estimated from remarks made by Lazar and Rasmussen (1964). Generally, it appears reasonable that the efficiency of water blanchers would be higher than that of conventional steam blanchers since water blanchers have less surface area for heat loss and they do not discharge as much steam to the surroundings at the feed and discharge.

Cost Estimates

Table 13 shows the capital cost of four blanchers. Since conventional steam blanchers are usually custom-fabricated, accurate purchase costs could not be obtained; therefore, it was decided not to include this type of blancher in the cost analysis. The hydrostatic steam blancher can be viewed as an improved version of a conventional steam blancher, and except for steam efficiency, its cost is probably similar to that of conventional steam blanchers. Except for the hot-gas blancher, equipment purchase costs were based on equipment manufactures' price quotations for a capacity of 4.5 kkg/hr (5 tons/hr) of snap beans (2.0 minute blanching time). The purchase cost

TABLE 13. CAPITAL INVESTMENT FOR BLANCHERS AND COOLERS

Item+	Vibratory Spiral Blancher-Cooler	Water Blancher	Hydrostatic Steam Blancher	Hot-Gas Blancher
1. Equipment purchase Cost	$108,000	$16,000	$ 87,000	$127,000
2. Delivery	5,000	1,000	4,000	6,000
3. Installation	22,000	3,000	17,000	25,000
4. Floor space	4,000	2,000	9,000	25,000
5. Indirect costs	35,000	6,000	30,000	46,000
	$174,000	$28,000	$147,000	$229,000

+

1. Equipment purchase costs were obtained from equipment manufactures, except for the Hot-Gas Blancher whose cost was taken from Ralls and Mercer (1974) and corrected to 1976 prices by the Marshall and Stevens Eqiupment Cost Index (Peters and Timmerhause, 1968). The water blancher and hot-gas blancher included an estimate of $5,000 for a cooling flume.

2. 5% of the equipment purchase cost.

3. 20% of the equipment purchase cost.

4. Floor space was vlalued at $\$270/m^2$. Floor space requirements are estimated as follows:
   Vibratory Spiral Blancher-Cooler ------ $15m^2$
   Water blancher ---------- $6m^2$
   Hydrostatic Steam Blancher ---------- $33m^2$
   Hot-Gas Blancher ---------- $93m^2$

5. 25% of the total of items 1 to 4.

of the hot-gas blancher was based on the costs reported by Ralls and Mercer (1974). Other items in estimating direct fixed capital were taken as percentages of equipment purchase cost (Peters and Timmerhaus, 1968). Floor space was valued at $\$270/m^2$ ($\$25/ft^2$). The purchase costs of the water blancher (reel type) and hot-gas blancher included $5,000 for a flume cooler. The vibratory spiral blancher-cooler and the hydrostatic steam blancher have the cooler as an integral part of the blancher.

Table 14 shows the labor, capital related, and utility and waste treatment costs for the four blanchers, as well as the basis used for calculating these costs. Since the open mesh conveyor belts used in the hydrostatic and hot-gas blanchers probably require more maintenance than the conveying systems used in the vibratory spiral or water blancher, higher maintenance costs were used for the former. There were no data available for the wasteload of hydrostatic steam blanchers; therefore, their wastewater costs was calculated from the wasteload of conventional steam blanching with flume cooling (Table 11). The water use and wasteload for flume cooling were added to those of water blanching and hot-gas blanching to get an overall cost of water and wastewater for these sytesms.

The low capital investment needed for a water blancher is the reason for its lowest cost of operation. The lower costs of steam, water and wastewater treatment for the vibratory spiral blancher-cooler as compared to the water blancher and flume were insufficient to compensate for the lower costs associated with capital investment. A doubling in the combined cost of utilities and wastewater treatment would give the vibratory spiral blancher-cooler an operating cost equivalent to that of the water blancher and flume. The hot-gas blancher's high cost is attributable mostly to high capital related costs, while that of the hydrostatic steam blancher is because of capital related and steam costs.

No attempt was made in these calculations to account for the loss of vegetable weight when air cooling is used. If frozen vegetables are valued at $\$440/kkg$ ($\$0.20/lb$), a 2% loss of yield resulting from air cooling as compared to flume cooling (Bomben, et al., 1975) would add the equivalent of $\$8.80/kkg$ to the cost of blanching and cooling since frozen vegetables are marketed by weight. Such a large penalty for air cooling cannot be economically justified. A standard other than weight for marketing frozen vegetables (e.g. number of vegetables per package or total solids per package) would be required to take full advantage of the wastewater reduction possible with air cooling. One should also note that at a price of $\$440/kkg$ for frozen vegetables, the entire cost of blanching and cooling is less than 2% of the cost of production. The small impact of blanching and cooling on the total cost of production gives the processor little economic incentive for capital investment in new blanchers or coolers.

Table 15 gives a comparison of the cost of the vibratory spiral blancher (without cooler) and the water blancher (without flume) as they would be used for canning vegetables. All other conditions of the cost calculation remain the same. The water blancher still gives the lower cost of operation, and here again a doubling in the combined cost of fuel, water and wastewater treatment would make the cost of operating the vibratory spiral blancher

TABLE 14. COST OF BLANCHING AND COOLING FOR FREEZING ($/kkg)*

Item+	Vibratory Spiral Blancher-Cooler	Water Blancher	Hydrostatic Steam Blancher	Hot-Gas Blancher
		Labor Costs		
1. Operating labor	0.63	0.63	0.63	0.63
2. Supervision, fringe benefits, laboratory, etc.	0.41	0.41	0.41	0.41
	1.04	1.04	1.04	1.04
		Capital Related Costs		
3. Maintenance	0.69	0.11	1.17	1.82
4. Depreciation	1.37	0.22	1.17	1.82
5. Insurance, taxes, other expenses	1.10	0.18	0.94	1.46
	3.16	0.51	3.28	5.10
		Utilities and Waste Treatment Costs		
6. Steam	1.24	1.75	3.91	1.40
7. Electricity	0.05	0.01	0.03	0.46
8. Water	0.00	0.66	0.64	0.64
9. Wastewater	0.01	0.15	0.14	0.12
	1.30	2.57	4.72	2.62
Total Cost	5.50	4.12	9.04	8.76

*Annual production - 4.5 kkg/hr x 14 hrs/day x 200 days/yr = 12,600 kkg/yr

+1. 1/4 man/shift for operation and 1/4 man/shift for cleaning (2 shifts/day) with average hourly wage = $5/hr: 2(2 + 2) $5/(14 x 4.5) = $0.63/kkg = $0.57/ton.

2. Supervision, fringe benefits, laboratory, supplies, etc. = 65% of operating labor.

3. Maintenance = 5% of direct fixed capital/yr for vibratory spiral and water blanchers and 10% of direct fixed capital for hydrostatic steam and hot-gas blanchers.

4. Depreciation = 10% of direct fixed capital/yr.

5. Insurance, taxes and other fixed expenses = 8% of direct fixed capital/yr.

6. Steam = $7.83 kkg of steam ($3.55/1,000 lb steam). Steam cost for Hot-Gas blancher includes cost of gas ($0.0013/MJ). (Johnnie and Aggarwal, 1977.

(continued)

TABLE 14 (continued)

7. Electricity = $0.00389/MJ ($0.018/kw-hr). (Johnnie and Aggarwal, 1977).

8. Water = $0.13/kL ($0.50/1,000 gal). (Johnnie and Aggarwal, 1977).

9. Wastewater = $0.018/kL ($0.062/1,000 gal), $0.022/kg BOD ($0.01/lb BOD), $0.044/kg SS ($0.02/lb SS). These costs are averages of values reported by Carroad (1975). Total wastewater cost is the sum of these costs for the snap bean wasteloads shown in Table 11, with the addition of flume cooling water (4900 l/kkg, 1.6 kg/kkg BOD) for the water and Hot-Gas blanchers (Bomben, et al. 1975).

equal to that of the water blancher. (A doubling in costs would be equivalent to a 7.2% annual increase for ter years). By removing the necessity of cooling, the fixed capital investment of the vibratory spiral equipment is reduced by 53%, while for the water blancher the removal of the flume reduced the investment by only 28%.

TABLE 15. COST OF BLANCHING WITHOUT COOLING FOR VIBRATORY SPIRAL BLANCHER AND WATER BLANCHER

	Vibratory Spiral Blancher	Water Blancher
	Labor Costs ($/kkg)	
1. Operating labor	0.63	0.63
2. Supervisor, fringe benefits, etc.	0.41	0.41
	1.04	1.04
	Capital Related Costs ($/kkg)	
3. Maintenance	0.33	0.08
4. Depreciation	0.65	0.16
5. Insurance, taxes, etc.	0.52	0.13
	1.50	0.37
	Utilities and Waste Treatment Costs ($/kkg)	
6. Steam	1.24	1.75
7. Electricity	0.01	0.01
8. Water		0.02
9. Wastewater	0.02*	0.02
	1.27	1.80
Total Cost	3.81	3.21
	Fixed Capital Investment($)	
Purchase Cost	51,000	11,400
Delivery	2,500	600
Installation	10,200	2,300
Floor Space	2,000(+)	1,700
Indirect Costs	16,400	4,000
	$82,100	$20,000

* Wasteload was taken as that of a conventional steam blancher.
+ 7.5m^2

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APPENDIX

TABLE A-1. EQUIPMENT SETTINGS FOR SNAP BEANS

Run No.	Heater* Eccentric Weight Setting	Number** of Weights on Holder	Holder Time on - off (sec)	Cooler Eccentric Weight Setting	Air Flow at Blower (m^3/min)	
SB-1 to SB-3	7	1	On continuously	7	150	up flow in cooler
SB-4 to SB-11	7	1	"	7	150	down flow in cooler
SB-12 to SB-28	7	1	"	9	150	" " " "
SB-29	6	1	20 - 10	9	150	" " " "
SB-30	6	1	On continuously	9	150	" " " "
SB-31	5	1	"	9	150	" " " "
SB-32 to SB-34	3	1	"	9	150	" " " "
SB-35	0	1	"	9	150	" " " "

* A setting of 0 gave a vibration amplitude of 0.95 cm (3/8 in.), 7 gave 0.64 cm (1/4 in.)
** With 1 weight the vibration amplitude was 0.32 cm (1/8 in.)

TABLE A-2. EQUIPMENT SETTINGS FOR LIMA BEANS

Run No.	Heater* Eccentric Weight Setting	Number** of Weights on Holder	Holder Time on - off (sec)	Cooler*** Eccentric Weight Setting	Air Flow at Blower (m^3/min)	
LB-1	7	1	On continuously	7	150	Up flow in cooler
LB-2 to LB-5	7	1	5 - 12.5	0	150	" " " "
LB-6 to LB-7	7	1	On continuously	0	85	" " " "
LB-8 to LB-10	7	1	"	0	140	" " " "
LB-11	7	1	"	0	140	" " " "
LB-12 to LB-13	7	1	10 - 10	0	150	" " " "
LB-14 to LB-15	7	1	10 - 10	0	85	" " " "
LB-16 to LB-17	0	1	10 - 10	9	150	Down flow in cooler

* A setting of 0 gave a vibration amplitude of 0.95 cm (3/8 in.) and 7 gave 4.8 mm (3/16 in.)
** With 1 weight the vibration amplitude was 0.32 cm (1/8 in.)
*** A setting of 0 gave a vibration amplitude of 0.96 cm (3/8 in.) and 7 gave 6.4 mm (1/4 in.)

TABLE A-3. EQUIPMENT SETTINGS FOR BRUSSELS SPROUTS, CAULIFLOWER AND BROCCOLI

Run No.	Heater* Eccentric Weight Setting	Number** of Weights on Holder	Holder Time on - off (sec)	Cooler*** Eccentric Weight Setting	Air Flow at Blower (m^3/min)
			Brussels Sprouts		
BS-1	10	1	10 - 40	9	150
BS-2 to BS-4	10	1	10 - 40	10	150
BS-5	10	1	10 - 30	10	150
			Cauliflower		
C-1	8	1	30 - 15	10	150
			Broccoli		
B-1	10	1	15 - 15	10****	150
B-2	10	1	Continuous	10****	150

* A setting of 0 gave a vibration amplitude of 0.95 cm (3/8 in.) and 7 gave 4.8 mm (3/16 in.)

** With 1 weight the vibration amplitude was 0.32 cm (1/8 in.)

*** A setting of 0 gave a vibration amplitude of 0.96 cm (3/8 in.) and 7 gave 6.4 mm (1/4 in.)

**** The setting was 2.5 cm (1 in.) beyond 10; 3.8 cm (1.5 in.) beyond 10 gave no vibration

TABLE A-4. MATERIAL BALANCE AND WASTELOAD

$$\text{Yield (\%)} = \frac{\text{Wet Weight of cooled vegetables (kg)}}{\text{Wet Weight of raw vegetables (kg)}} \times 100$$

$$\text{Solids loss (\%)} = \frac{\text{Hydraulic load (L/kkg)}}{1000} \times \frac{\text{TS in effluent (\%)}}{\text{TS in raw vegetables (\%)}} \times 100$$

$$\text{Hydraulic load (L/kkg)} = \frac{\text{Weight of effluent (kg)}}{\text{Weight of raw vegetables (kg)}} \times 1000 \text{ (L/kg)}$$

$$\text{BOD (kg/kkg)} = (\text{BOD analysis in mg/L}) \times \text{hydraulic (L/kkg) load} \times 10^{-6}$$

TOC and SS were calculated similarly to BOD

TABLE A-5. EFFLUENT ANALYSES - SNAP BEANS

Run Number*	Total Solids			SS	TOC	BOD
	Raw Veget. (%)	Effluent+ (%)	Effluent++ (mg/L)	Effluent (mg/L)	Effluent (mg/L)	Effluent (mg/L)
SB-1 P	10.76	--	--	--	12000	15600
SB-2 P	10.76	2.37	--	1151	9750	16200
SB-3 P	10.76	2.43	--	1500	9880	15000
SB-4 P	10.35	1.96	--	--	8680	--
SB-5 P	10.25	--	--	--	--	--
SB-6 P	9.23	3.18	--	--	11500	--
SB-7 P	10.65	--	--	--	--	--
SB-8 P	10.45	3.39	--	--	12300	--
SB-9 P	10.05	3.01	--	--	11700	--
SB-10 P	10.98	3.63	--	--	14600	--
SB-11 P	11.78	3.19	--	--	12000	--
SB-12 P	12.92	Not enough effluent for sample				
SB-13 P	13.54	3.79	31200	5610	14200	--
SB-14 B	13.51	Not enough effluent for sample				
SB-15 B	9.53	3.39	29700	4140	12130	--
SB-16 P	13.31	3.12	28700	3660	10700	--
SB-17 B	14.69	Not enough effluent for sample				
SB-18 P	14.22	" "	"	" "		
SB-19 B	15.59	" "	"	" "		
SB-20 B	16.21	" "	"	" "		
SB-21 B	9.56	3.99	39000	4310	14300	--
SB-22 B	12.67	Not enough effluent for sample				
SB-23 B	15.88	" "	"	" "		
SB-24 C	9.28	3.87	38900	4300	13500	19200
SB-25 B	9.49	2.97	28900	3260	10700	--
SB-26 P	12.84	2.89	29700	3200	10500	--
SB-27 C	10.46	4.20	40000	4600	15300	25200
SB-28 C	9.35	3.59	35000	3390	12900	22200
SB-29 B	9.43	3.38	32200	3410	12100	--
SB-30 C	10.23	3.80	36000	4000	14600	24600
SB-31 C	9.90	3.29	30500	3750	11250	18600
SB-32 B	9.33	2.69	24800	2600	9000	--
SB-33 B	8.86	2.46	24600	2700	8250	--
SB-34 P	9.84	2.67	26500	--	--	--
SB-35 C	10.16	2.81	25700	2920	10800	23400
SB-36 C	10.97	3.48	32400	4350	13800	25800
SB-37 C	10.75	3.54	34300	4300	13800	21000

*P = preliminary run
B = batch run
C = continuous run
+ Using AOAC, 1965
++ Using EPA, 1971

TABLE A-6. EFFLUENT ANALYSES - LIMA BEANS

Run Number*	Total Solids: Raw Veget. (%)	Total Solids: Effluent+ (%)	Total Solids: Effluent++ (mg/L)	SS Effluent (mg/L)	TOC Effluent (mg/L)	BOD Effluent (mg/L)
Pilot Plant						
LB-1 P	36.12	5.40	--	10700	14300	18800
LB-2 P	Run stopped					
LB-3 P	--	4.63	--	5180	13800	15600
LB-4 P	Run stopped					
LB-5 P	" "					
LB-6 P	--	--	--	10800	13800	19800
LB-7 P	41.29	7.21	--	14200	18200	29400
LB-8 B	40.65	4.53	43000	8900	13800	21200
LB-9 B	38.46	7.50	71500	17400	20200	--
LB-10 C	Run stopped					
LB-11 C	40.86	7.30	71800	14800	17700	--
LB-12 C	40.72	7.72	77800	17500	19800	--
LB-13 C	41.60	7.53	68300	14900	18300	28800
LB-14 C	35.92	7.11	69800	--	24800	19800
LB-15 C	36.09	6.65	65400	27200	22800	28200
LB-16 B	38.70	Not enough effluent for sample				
LB-17 C	41.82	--	--	--	--	
Production Line						
LBPL-1						
blanching	36.08	1.14	10400	762	3240	5810
cooling		1.69	3330	280	708	1700
LBPL-2						
blanching	35.35	1.24	12100	1840	3670	8200
cooling		0.238	2390	84	230	580
LBPL-3						
blanching	35.37	1.54	15000	1830	4700	8500
cooling		0.542	5370	388	1400	3200

* P = preliminary run
B = batch run
C = continuous run
PL = production line

+ Using AOAC, 1965
++ Using EPA, 1971

TABLE A-7. EFFLUENT ANALYSES - BRUSSELS SPROUTS, CAULIFLOWER AND BROCCOLI

Run Number	Total Solids			SS	TOC	BOD
	Raw Veget. (%)	* (%)	+ (mg/L)	(mg/L)	(mg/L)	(mg/L)
Brussels Sprouts						
BS-1 P	--	--	--	--	--	--
BS-2 P	14.2	Not enough effluent for sample				
BS-3 P	14.1	2.76	25800	3490	9970	--
BS-4 P	13.2	2.08	20740	2290	7500	--
BS-5 P	Run stopped					
Cauliflower						
C-1 P	8.45	Not enough effluent for sample				
Broccoli						
B-1 P	10.1	Not enough effluent for sample				
B-2 P	11.8	3.53	33300	8230	13600	--

* Using AOAC, 1965
+ Using EPA, 1971

TABLE A-8. CALCULATION OF THEORETICAL STEAM FLOW REQUIRED FOR BLANCHING

Conditions:

Raw vegetable temperature - 16°C
Blanched vegetable temperature - 88°C
Heat of condensation of steam - 2256 kJ/kg

With no heat losses:

Heat in from condensing steam = heat out with product

$$\text{Theoretical steam requirement} = \frac{(4.19)(88 - 16)}{2256} \times 1000$$

$$= 134 \frac{\text{kg steam}}{\text{kkg raw vegetable}}$$

For Hot-Gas Blancher (Ralls & Mercer, 1974) blanching peas:

Steam use = 170 kg/kkg

Natural gas = 1.64 m^3/kkg
1.64 x 37300 kJ/m^3 = 61100 kJ/kkg
steam equivalent = 61100/2256 = 27.1 kg/kkg

Electrical power = 91.4 MJ/kkg
(circulating fan) steam equivalent = 91.4 x 10^6/(2256 x 10^3) = 40.5 kg/kkg

Total steam equivalent = 170 + 27.1 + 40.5 = 238 kg/kkg

$$\text{Efficiency} = \frac{134}{238} \times 100 = 56\%$$